DEPOSITIONAL AND DIAGENETIC HISTORY OF THE PERMIAN ROCKS IN THE MEERS VALLEY, SOUTHWESTERN, OKLAHOMA

By

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PREFACE

The primary objective of this thesis is to describe the sedimentary geology of the Permian rocks in the Meers Valley (north of the Wichita Mountains), Oklahoma. This thesis describes processes and controls which operated during the time of Permian deposition. Measured sections and petrographic analyses were used in this study.

The author expresses her deepest appreciation to her major thesis adviser, Dr. R. Nowell Donovan, for his neverending guidance and support. Appreciation is also expressed to her thesis committee members, Dr. Ibriam Cemen and Dr. Victor Vere, for their advice and assistance.

A special thanks goes to Mr. and Mrs. Charlie Oliver (manager of the Kimball Ranch) who granted access to their land for field studies and as a field "home base." Thanks are also due to other landowners of the area, especially Mr. Brown and the Deitrich family, for their friendly hospitality.

The author acknowledges an honorarium from the Oklahoma Geologic Survey to help defray field and preparation costs of this thesis.

Appreciation goes to all the faculty and graduate students, especially Becky Sweet and Debbie Ragland, who gave friendship and support throughout my stay at Oklahoma

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The author expresses gratitude to her parents, Jim and Joan Collins, and to her brothers, Jeb and John. Their love and encouragement were invaluable.

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CHAPTER I

INTRODUCTION

Statement of Purpose

This thesis describes the Permian rocks in the Meers Valley, north of the Wichita Mountains, southwest Oklahoma. The work forms part of an ongoing study in the Wichita Mountains area supervised by Dr. R. Nowell Donovan of Oklahoma State University, Dr. M. Charles M. Gilbert of Texas A & M University, and the Oklahoma Geological Survey.

Emphasized in this study are the depositional and diagenetic histories of the Permian shales, sandstones and conglomerates.

Location of the Study Area

The Meers Valley is an exhumed Permian valley in the Wichita Mountain uplift (Figure 1). The Meers Valley lies between the Wichita igneous complex and the Slick (Limestone) Hills (Figure 2). The Wichita igneous complex to the south consists of a variety of Cambrian gabbros, rhyolites, and granites, To the north are folded and faulted Cambro-Ordovician carbonates (unconformable on rhyolite) which form the Slick Hills (Figure 3). Permian rocks in the Meers Valley are composed of alluvial detritus

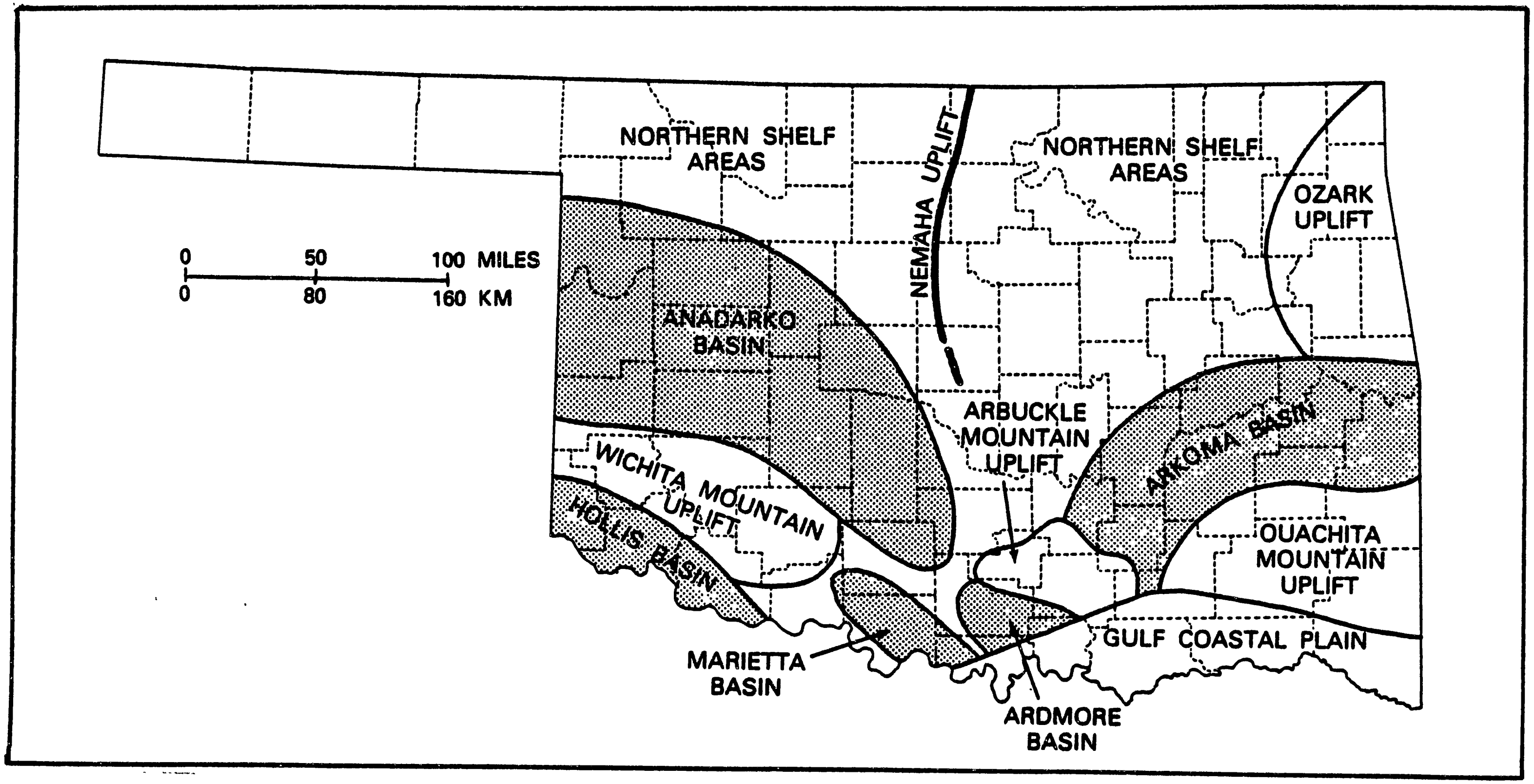
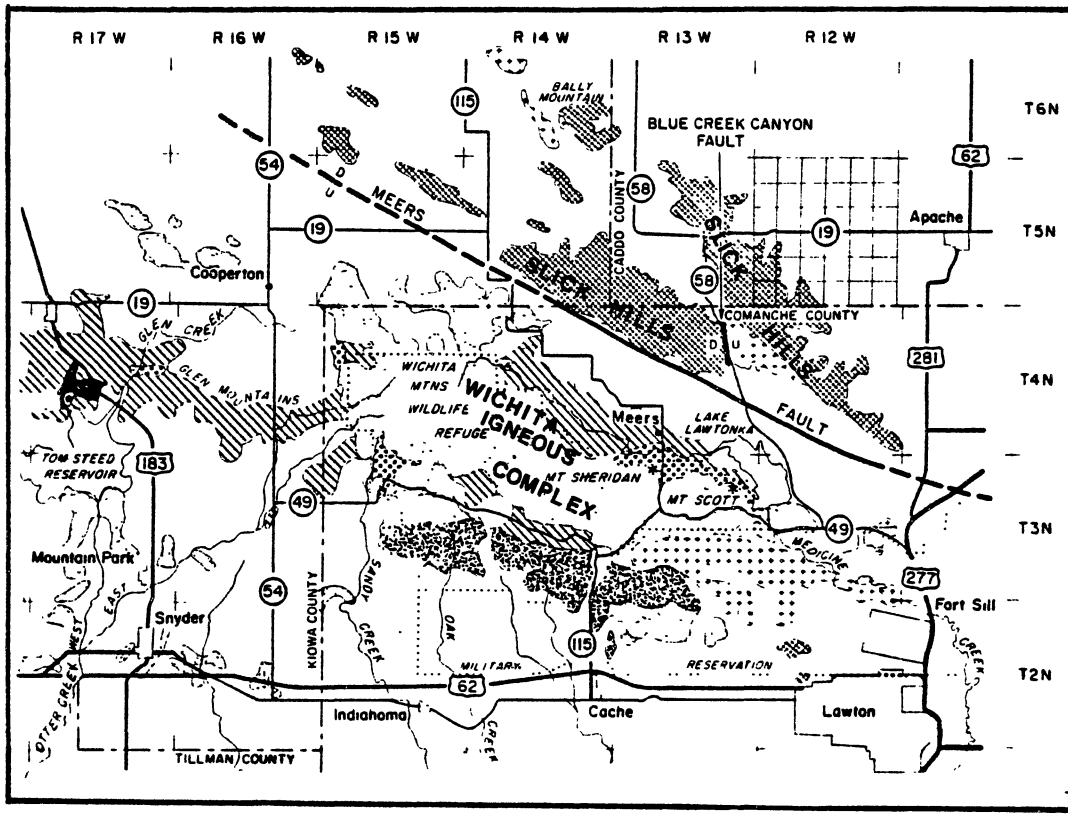


Figure 1. Major Geological Provinces of Oklahoma. Study Area is Located in The Wichita Mountain Uplift (after Johnson, 1972)



CAMBRIAN (500 - 525 m.y b.p.)
Cold Springs Breccia
Wichita Granite Group
Coarser - grained Sills (Reformatory in West; Quanah in East)
Finer - grained Sills
Carlton Rhyolite Group

PRECAMBRIAN - CAMBRIAN (?)
Raggedy Mountain Gabbro Group
Roosevelt Gabbros
Glen Mountains Layered Complex

PERMIAN AND QUATERNARY
Shown undifferentiated and without pattern

CAMBRIAN - ORDOVICIAN
Arbuckle Group
Timbered Hills Group

Figure 2. Geological Map of Wichita Mountains Area (after Gilbert, 1982)

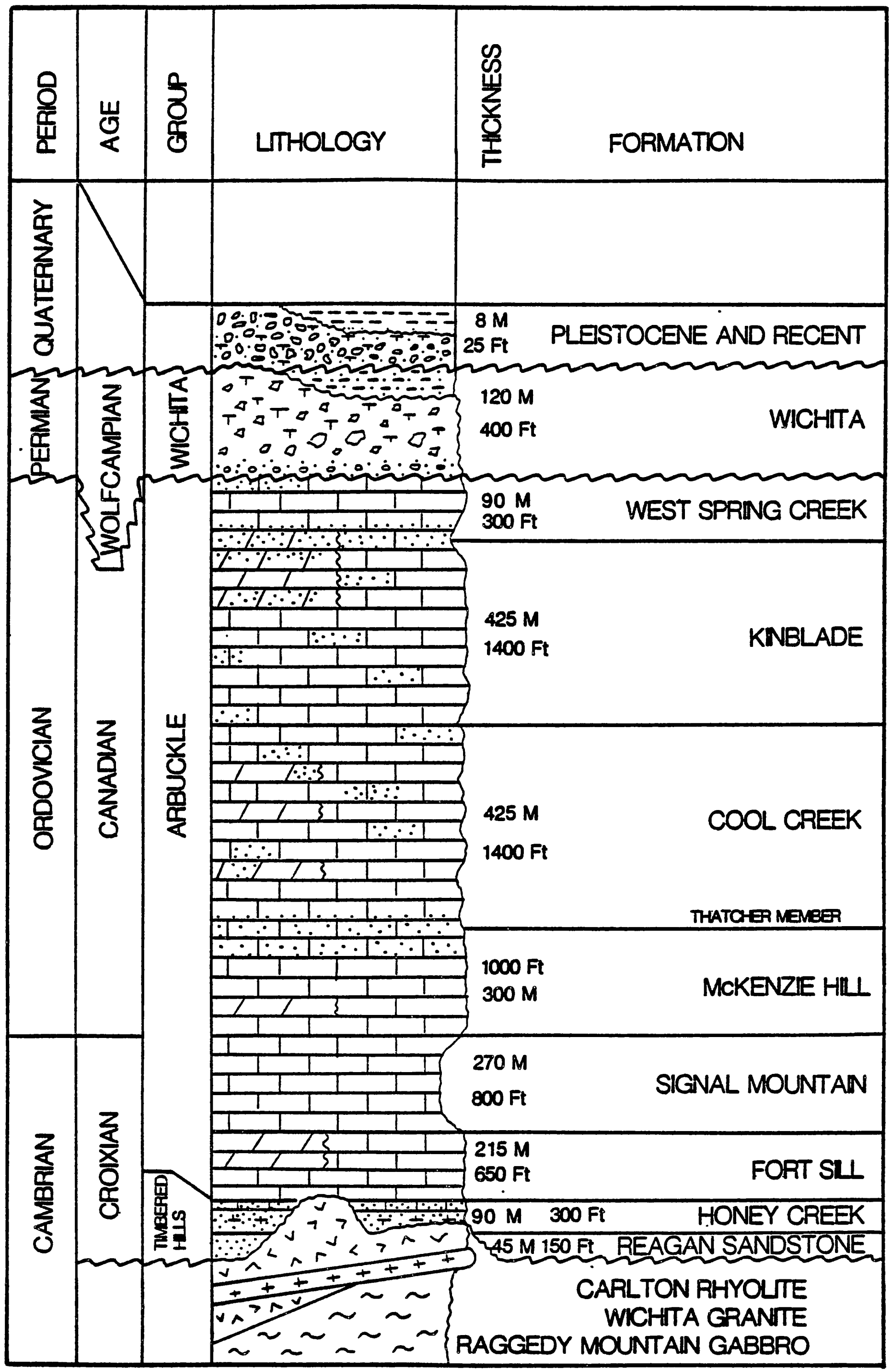


Figure 3. Stratigraphic Column of the Rocks in the Meers Valley Area

from both the Wichita Mountains and the Slick Hills.

The Meers Valley lies in parts of T3-5N, R12-14W in Caddo, Comanche, and Kiowa counties. The valley is roughly parallel to the trend of the Meers Fault (c. 050-310) (Figure 2).

Previous Investigations

The Permian rocks in the Meers Valley have not been described separately prior to this study. However, several authors have discussed Permian sedimentation in the general Wichita Mountains area. Early authors noted the Permian rocks but did not fully describe them. Bain (1900) called them the Geronimo Series and described them as shales interbedded with limestone, granite, and rhyolite conglomerate but offered no depositional mechanism. Taff (1904) stated that the coarse Permian facies represents the near shore phase of the Permian sea, deposited simultaneously with the finer, offshore Permian facies. Hoffman (1930) expressed the same views as Taff; however he considered many of the conglomerates to be Pleistocene gravels not Permian. Merritt and Ham (1941) described isolated outcrops of granite, gabbro, and anorthosite conglomerate cemented with opal and zeolite. They designated these the Tepee Creek Formation which they considered to be of Precambrian age. Mayes (1947) later declared these rocks to be Permian in age.

Chase (1954) was the first to conduct an in-depth study of the Permian conglomerates which he named the Post Oak Conglomerate. He considered them equivalent to the Upper Pontotoc Group, and the Wellington and Lower Garber Formation.

Chase identified and described four types of Post Oak Conglomerate: i) dominantly limestone clasts, ii) dominantly granite clasts, iii) dominantly rhyolite clasts, and iv) characterized by opal and zeolite cements (Figure 4).

Chase maintained the depositional environment put forth by Taff (1904) and suggested that the conglomerates mark the latest significant orogenic movement in the Wichita Mountains area.

Later, Chase, et al. (1956) noted that the Post Oak Conglomerate ranges from 400-600 feet thick. They also noted that the Post Oak Conglomerate has been cut by the latest movement of the Meers Fault.

A series of papers by Al Shaieb et al. (1977, 1978, 1980, 1982) redefined the depositional environment. On the basis of such parameters as sedimentary structures, paleocurrents, and textures of the conglomerates and sandstones, they inferred an alluvial fan/braided stream complex. Also supporting this hypothesis was the recognition of the pedogenic carbonates which had previously been interpreted as marine transgressive limestones. In addition these authors provided detailed petrographic and field descriptions of the rocks.

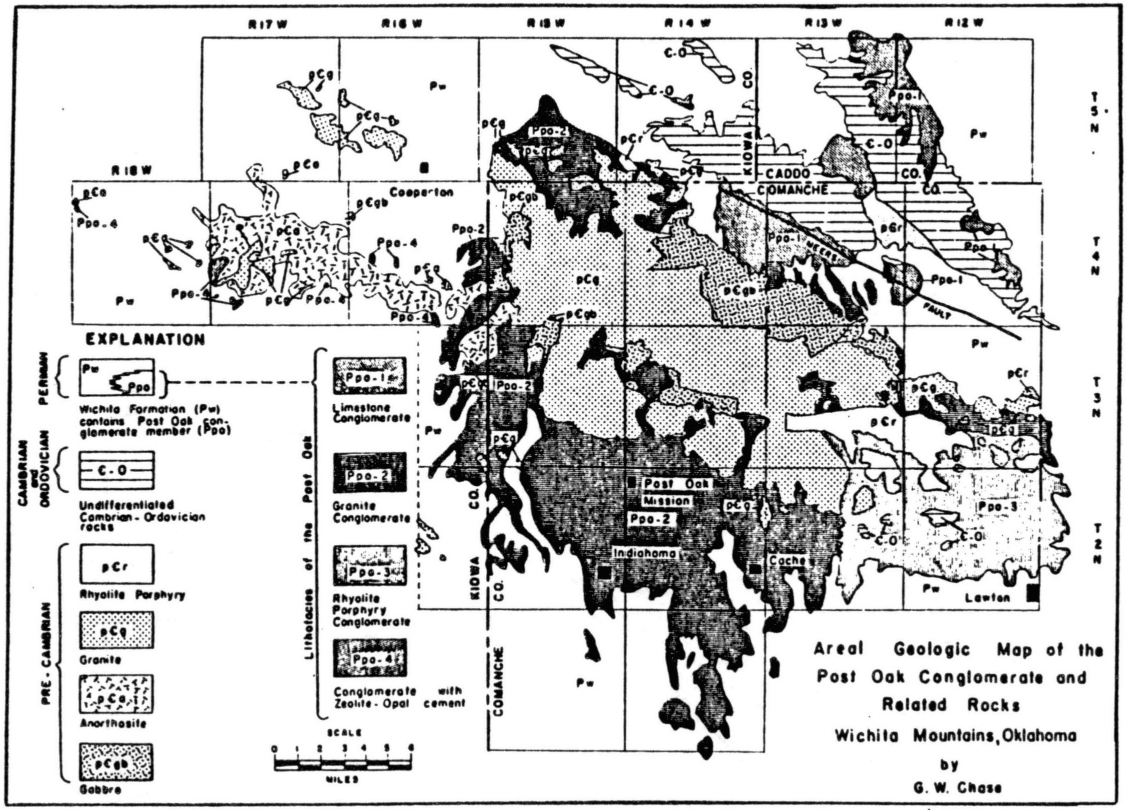


Figure 4. Geological Map of the Wichita Mountains Area; Permian Conglomerates are Differentiated According to Clast Compostition (after Chase, 1954)

Most previous work has been conducted south of the Wichita Mountains. Nonetheless, it provides an insight into the deposits of the Meers Valley.

The Geological Setting

The study area is located in the Pennsylvanian Wichita Mountain uplift. This uplift is situated within an earlier, more extensive tectonic system called the Southern Oklahoma aulocogen. Tectonic elements of the aulocogen were reactivated by this uplift.

Hoffman et al. (1974) interpreted the Southern Oklahoma aulocogen as the failed arm of an early Paleozoic rift system that separated the North American craton from the continental crust to the east and southeast (Figure 5). Rifting of the aulocogen began in Late Precambrian time and was followed by a period of subsidence. Thick igneous suites of granites, rhyolites, and gabbros accumulated in the aulocogen in early Cambrian time. These were succeeded by the deposition of up to 3100 meters of carbonates and shales from Late Cambrian to Late Devonian time (Hoffman et al. 1974). The aulocogen was compressed and destroyed during Late Paleozoic time as a result of the closure of the Ouachita Mountain belt (Brewer, 1982). This compression, which was accompanied by a degree of left-lateral shear, resulted in a complex pattern of fault-bounded basins and uplifts formed along lines of previous structural weaknesses (Figure 6).

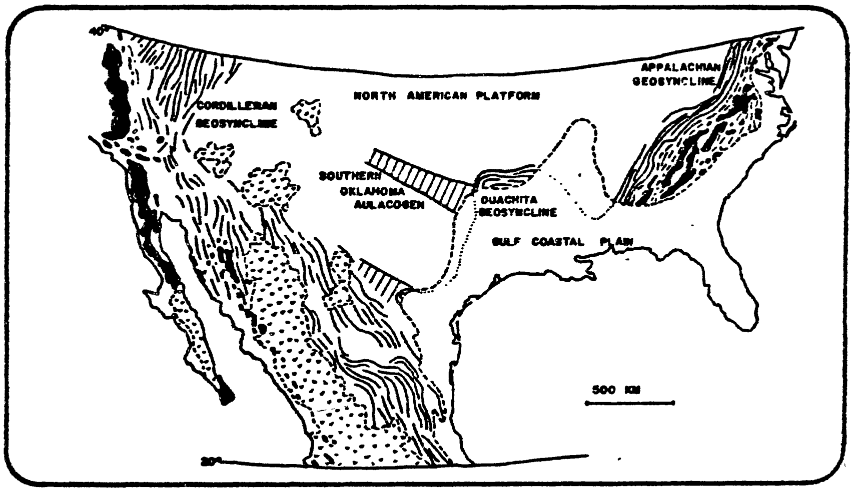


Figure 5. Map of Part of North America Showing the Location of the Southern Oklahoma Aulocogen (after Hoffman et al. 1974)

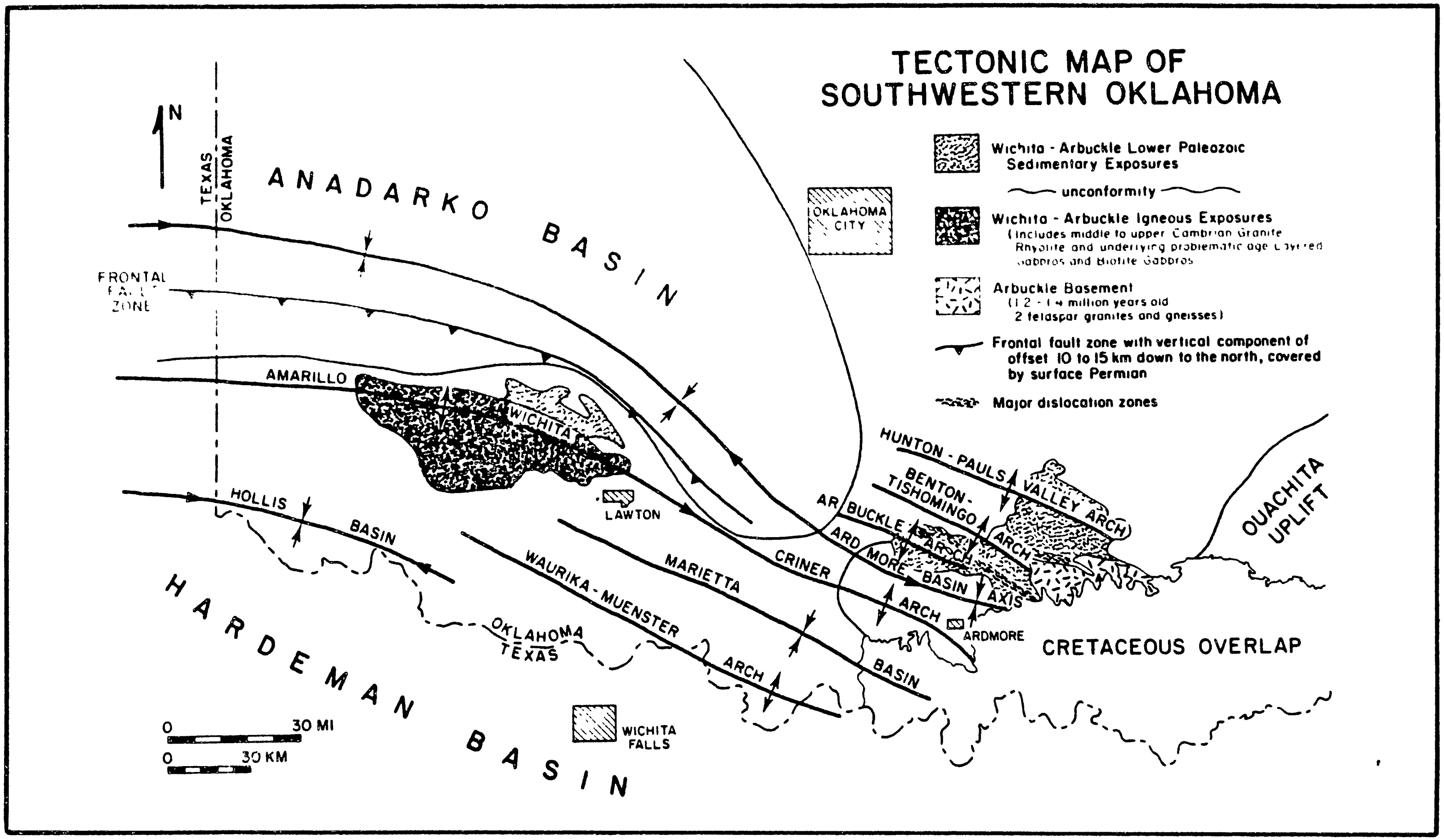


Figure 6. Tectonic Map of Southwestern Oklahoma
(after Gilbert, 1982)

Webster (1980) stated that there were two main pulses of deformation in the Pennsylvanian time, the "Wichita orogeny" and the "Arbuckle orogeny". The earlier (Morrow-Des Moinesian) Wichita orogeny resulted in the Amarillo-Wichita Mountain uplift with approximately 10,000 meters of vertical displacement along a series of sub-parallel faults. Webster interpreted these faults as high angle reverse structures. But, Brewer (1982) suggested that they are oblique, combining wrench and thrust movements. Walper (1970) was the first to note that the faults in the Frontal Wichita zone are arranged in an en echelon pattern trending c.105-285.

During the dismemberment of the aulocogen, the Ardmore and Anadarko basins became the principle depocenters. The Anadarko Basin was filled by over 7000 meters of Pennsylvanian and Permian sediments (Webster, 1980). Gilbert (1982) suggested that the Wichita Mountains provided much of the earliest deposited detritus, principally the granite wash. As tectonism waned in the Wichita Mountains, additional sediments were supplied to the Anadarko Basin from the Ouachita tectonic belt to the southeast. Gilbert noted that eventually the Wichita Mountains were buried by Permian sediments, and he assumed that Cretaceous units ultimately covered the area. It is pertinent that Cretaceous rocks have been mapped north of the field area in Washita county (Miser, 1954).

Tectonics of the Meers Valley

In a more local setting it is important to examine the Meers Fault in conjunction with the history of the rocks in the Meers Valley. Gilbert and Donovan (1984) stated that the Meers Fault had considerable pre-Permian movement which resulted in an apparent stratigraphic downthrow to the north. They also suggested that there was a reversal of movement along the fault in early Permian time, resulting in the uplift of the Slick Hills to the north. Gilbert and Donovan suggested that the reversal of movement was possibly due to relaxation of earlier compressive stress along the zone.

Latest movement along the Meers Fault has clearly cut the Post Oak Conglomerate in the valley (Figure 7). Donovan et al. (1983) interpreted this as a Quaternary rejuvenation. They stated that there were two components of movement: downthrow to the south (maximum 7 meters) and left-lateral displacement of a similar dimension.

Figure 7. Photograph of the Recent Meers Fault Trace in the Permian Rocks of the Meers Valley (Photo Courtesy of R. Nowell Donovan)

CHAPTER II

THE STRATIGRAPHIC POSITION OF THE "POST OAK CONGLOMERATE" IN THE MEERS VALLEY

Chase (1954) assigned the term "Post Oak Conglomerate" to the Permian conglomerates in the Meers Valley. The term "Post Oak Conglomerate" is actually a term of convenience used to describe surface outcrops of conglomerates which are unique to the Wichita Mountains area. Previous authors have tried to correlate these conglomerates as facies equivalents of sandstones and shales in the rest of southwestern Oklahoma. Thus, Chase (1954) and Miser (1954) assigned the "Post Oak Conglomerate" (as a member) to the Wichita Formation. The latter is equivalent to the Lower Garber Sandstone, The Wellington Formation, and the Upper Pontotoc Group in southcentral Oklahoma (Figure 8) (Miser, 1954). Havens (1977) correlates the "Post Oak Conglomerate" with the Hennessey Shale and the Garber Sandstone (Figure 9).

However, formal stratigraphic practice is inappropriate in the analysis of the conglomerates in the Wichita Mountains. The term "Post Oak Conglomerate" is descriptive of a facies of rock shed from the Wichita

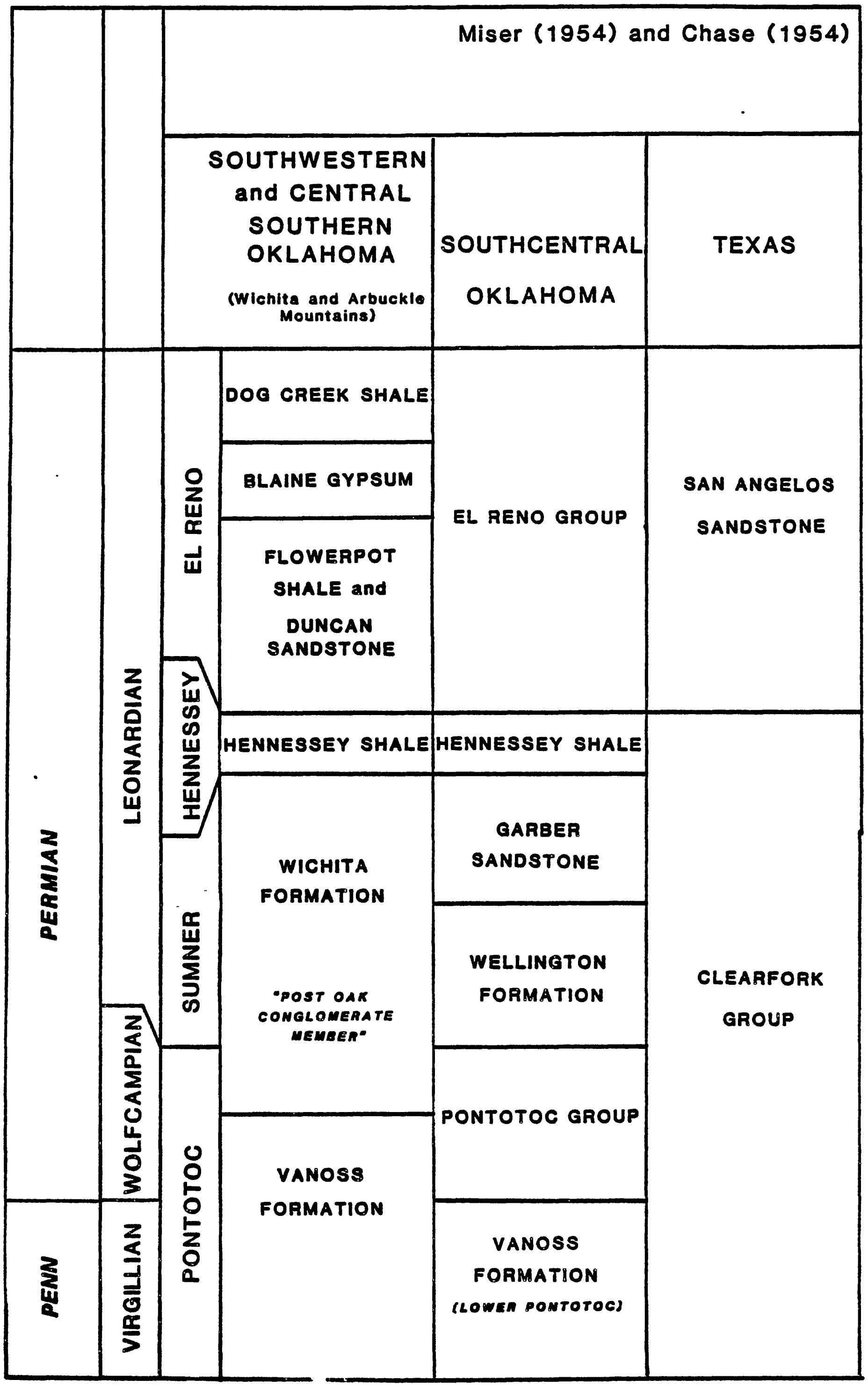


Figure 8. Stratigraphic Column of Late Pennsylvanian and Early Permian Strata of Southern Oklahoma and Texas According to Miser (1954) and Chase (1954)

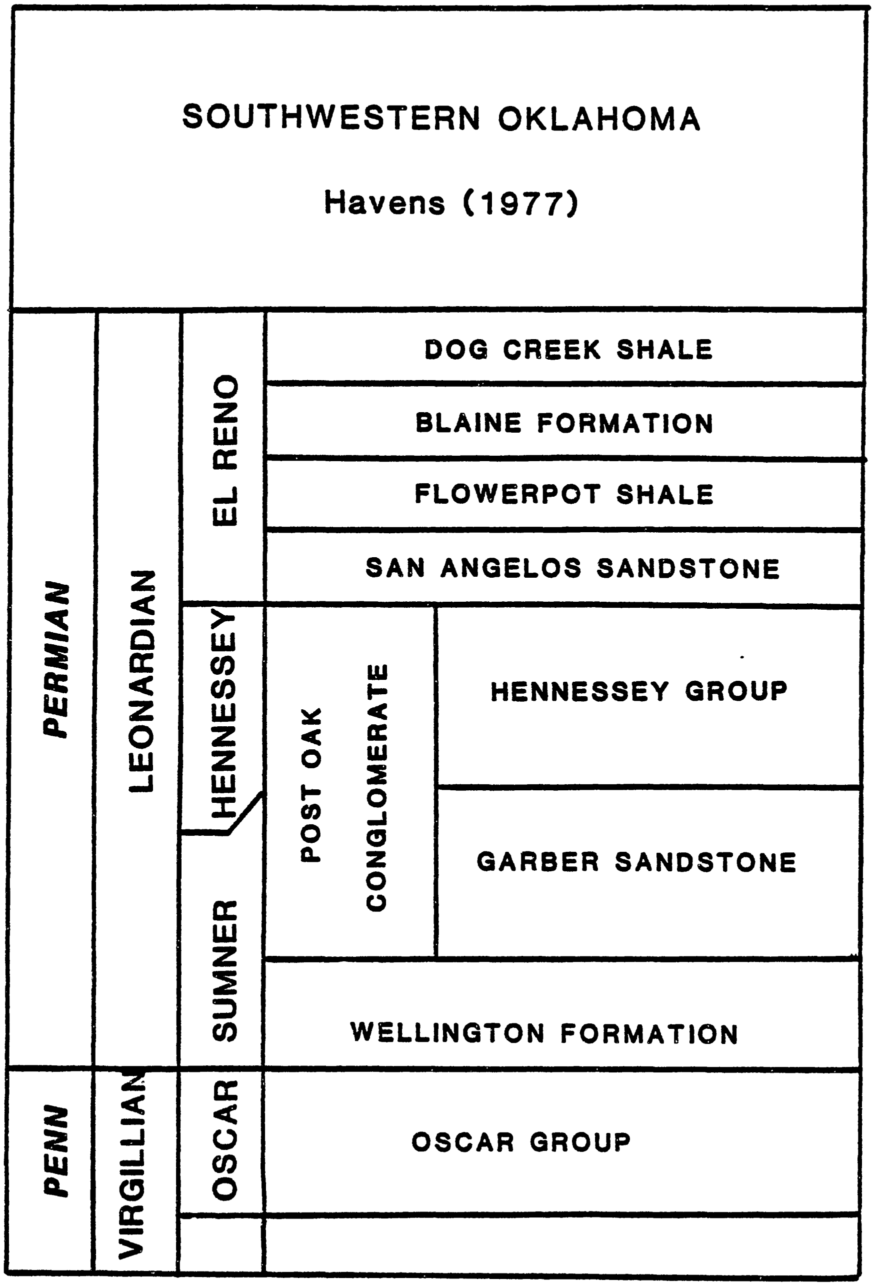


Figure 9. Stratigraphic Column of Late Pennsylvanian and Early Permian Strata of Southwestern Oklahoma According to Havens (1977)

Mountain block (including the Wichita Mountains and the Slick Hills) during and after periodic episodes of tectonically controlled uplift.

Given such a control (which operated from Pennsylvanian to Middle Permian time), it is inherently unlikely that precise correlation can be made with deposits distal to the Wichita Mountains. Furthermore, evidence will be advanced in this thesis that the Meers Valley conglomerates are a greatly condensed succession containing numerous hiati.

The formal status of the term "Post Oak Conglomerate" is also weakened by its use as a term covering only surface exposures. Such usage is clearly incompatible with any suggestions of chrono-stratigraphic equivalence (what is being equated is simply the present surface of erosion). Nevertheless, the term has some merit in an informal sense as being descriptive of a homotaxial facies.

The classifications of Chase (1954), Miser (1954), and Havens (1977) suggest (in part) that the "Post Oak Conglomerate" is equivalent to younger strata than this research suggests, at least in the Meers Valley. Figure 10 shows a modification (used in this thesis) of Miser (1954) and Chase's (1954) classifications for the classification of the Meers Valley "Post Oak Conglomerates". It is emphasized that the correlation suggested is of general character; no individual lithostratigraphic horizons can be traced from the Meers Valley to surrounding areas.

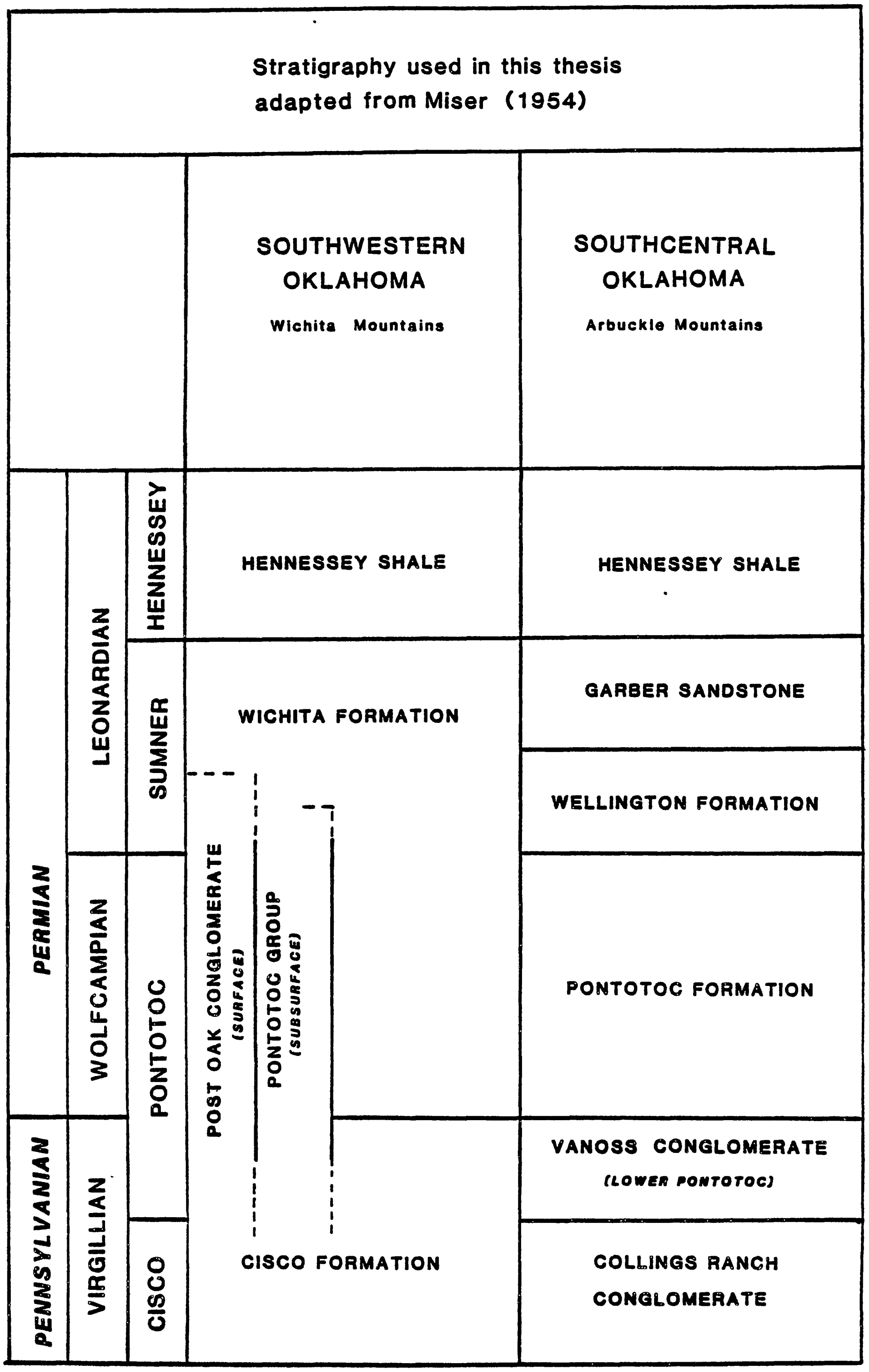


Figure 10. Stratigraphic Column of Late Pennsylvanian and Early Permian Strata Used in This Thesis (adapted from Miser, 1954)

Evidence supporting this modification in classification includes field relationships demonstrating that (in part) the "Post Oak Conglomerate" is stratigraphically older than both the Hennessey Formation and the Garber Sandstone. Also, the granite-clast conglomerates appear to have been deposited under different climatic controls than the other deposits in the Meers Valley (refer to Chapter V). These conglomerates show evidence of deposition in a more humid environment rather than in the semiarid climate which is known in the Permian. It has also been suggested that some of the boulder-breccia deposits in the Meers Valley record a direct response to tectonism (Donovan et. al., 1985). If tectonics ended in Late Pennsylvanian time (as was suggested by Webster, 1980); then at least these boulder-breccia deposits in the Meers Valley are pre-Permian. The alternative interpretation is that tectonism was much longer lasting than is suggested by Webster (1980).

CHAPTER III

DESCRIPTION OF THE PERMIAN ROCKS IN THE MEERS VALLEY

Outcrop character

Well-exposed sections are not common in the Meers Valley. Pebbles scattered about the landscape are usually the only evidence of underlying conglomerates. Stream cuts provide the most useful sections. These are usually about 3 meters deep but some occur up to 10 meters. Some well-exposed sections are provided by road cuts.

Location of the Best Quality Exposures

Particularly valuable exposures recognized in the study area are (plate 1):

i) of limestone-clast conglomerates - along the banks of a large unnamed tributary to Medicine Creek, section 17, T4N, R13W.

ii) of granite-clast conglomerates - along the ridge west of the Meers Cemetery, section 20, T4N, R13W.

iii) of (hybrid) limestone/granite-clast conglomerates - along the banks of Lake Lawtonka, section 6, T3N, R13W.

iv) of sands and shales - "Brown´s outcrops", NW 1/4, section 2, T3N, R12W.

v) of megabreccia horizons - sections 16, 17, 18, 19, and 20, T4N, R13W.

vi) of dolomite horizons - occurring in the limestone megabreccia horizons, most common in section 19, T4N, R13W.

vii) of calcretes - along the banks of Lake Lawtonka, section 6, T3N, R13W.

The most obvious and straightforward exposure of the granite-clast conglomerate/limestone-clast conglomerate contact lies in the NE 1/4, SE 1/4, section 19, T4N, R13W. This exposure is especially useful as it contains each type of conglomerate.

Summary of Geometric Relationships Observed in the Field

Conglomerates, sandstones, and shales in the Meers Valley each exhibit different geometries and sedimentary structures. Three geometries of conglomerate deposits are present. The first comprises a complex of multistoried erosive-based channel deposits up to 5 meters thick and 8 meters wide which may be deeply incised into the underlying beds (Figure 11). The second conglomerate geometry consists of lenticular beds which are not incised into the substrate. The third geometry consists of multistoried flat-based sheets up to 1.5 meters thick and 15 meters wide (Figure 12). Only in the finer conglomerates are bedforms such as parallel laminations and trough crossbedding preserved (Figure 13). Shale layers up to 1 meter thick

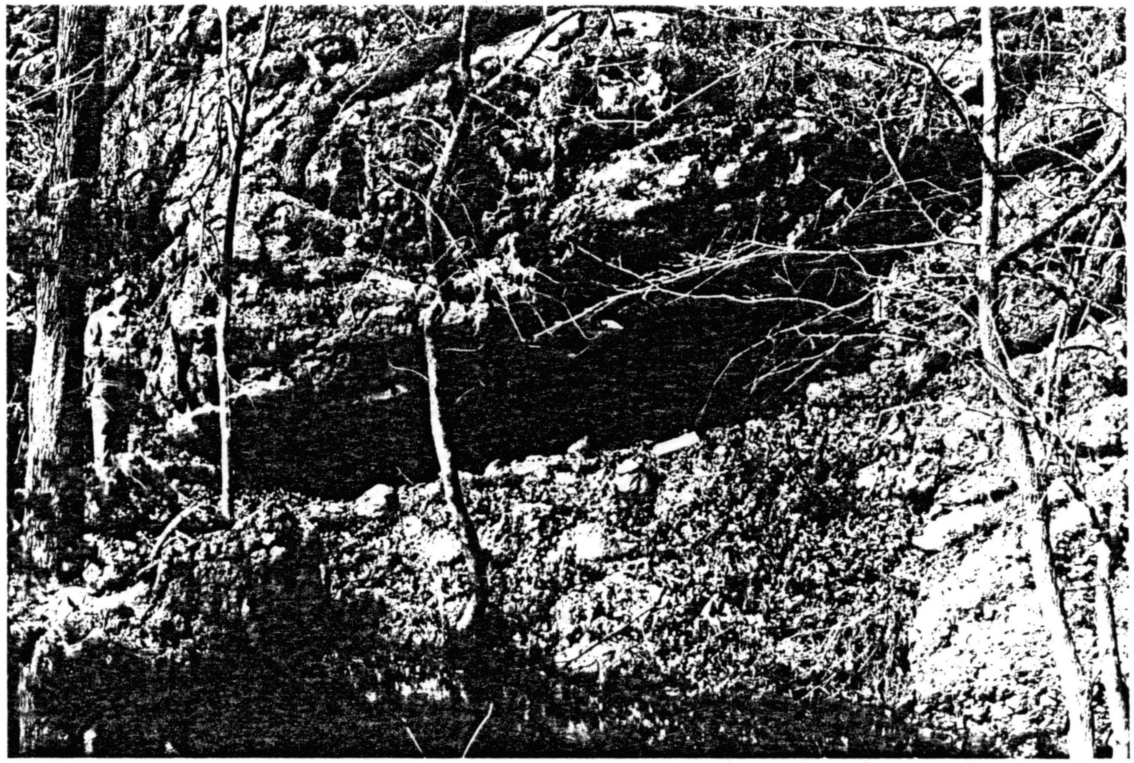


Figure 11. Erosive-based Limestone-clast Conglomerate Channel

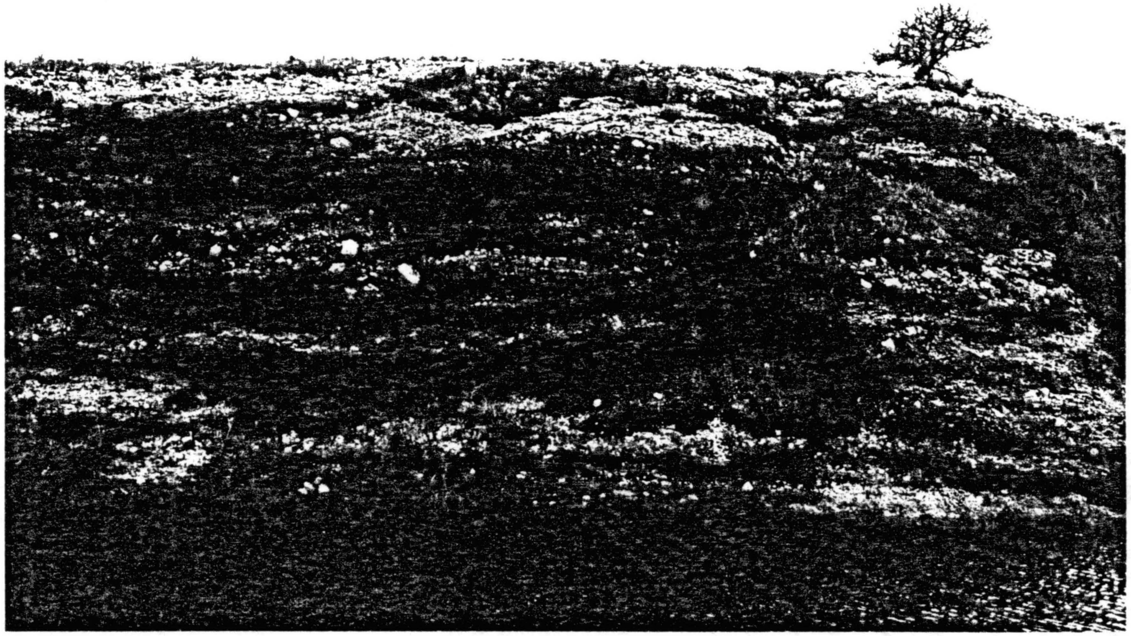


Figure 12. Multi-storied, Flat-based Limestone-clast Conglomerate Channels

Figure 13. Planar Crossbedding in a Limestone-clast Conglomerate Channel

may punctuate some of the conglomerate sequences. Such layers may be impregnated by caliche.

Erosive-based lenticular sandstone channels up to 2 meters thick and 20 meters wide. These are most common in the southeastern part of the Meers Valley. Such channels are usually interbedded with sequences of shale. The sandstones exhibit some basal conglomerate lags, parallel lamination, and trough crossbedding. Many individual laminae in the sandstones are accented by opaque heavy minerals (Figure 14). Some upward-fining graded bedding occurs, but for the most part the sandstones are apparently featureless.

Shales are reddish, more rarely green and gray. They are poorly exposed. Some show silt-mud laminations, others consist entirely of mud. As a result, fissility is a variable quality. Some mudcracks are present; these appear to be of subaerial origin.

All of the above mentioned primary lithologies have acted as hosts for calcrete formation. Calcretes vary in thickness from a few centimeters to 3 meters. They may consist of a few glaebules and sparse rhizoliths or they may be horizons of complete carbonate impregnation (discussed in Chapter IV).

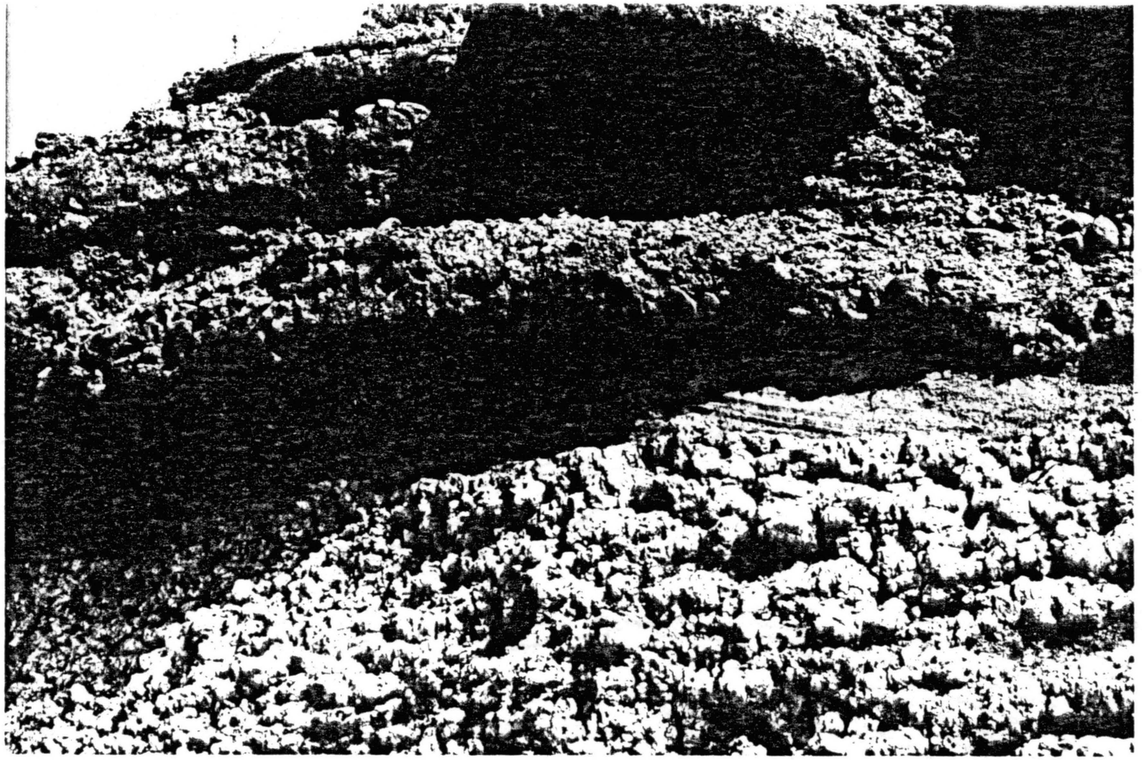


Figure 14. Magnetite and Illminite Accenting Trough Cross-bedding in a Sandstone at Lake Lawtonka

Petrology and Petrography

Granite-clast Conglomerates

Conglomerates containing granite clasts are pinkish-orange to maroon in color (Figure 15). Outcrops of such conglomerates are rare as they lie stratigraphically beneath limestone-clast conglomerates in the Meers Valley. Bedform geometries are difficult to determine because present day weathering is hydrolysing feldspars and in some cases is producing deposits of "grus-like" character. Most of the cement that is present is either hematitic or composed of clays, therefore the conglomerates are very friable. Carbonate cement is very rare in this lithology.

The granite-clast conglomerates can be classified as paraconglomerates; the sandy matrix is often 50% of the rock. The granite clasts range from 1 to 30 centimeters in diameter and are very well rounded (Figure 16).

Most granite clasts have a granophyric texture (Figure 17) which is typical of the Mount Scott Granite. As this granite forms the southern margin of the Meers Valley, source determination seems obvious.

Limestone-clast Conglomerates

Limestone-clast conglomerates are by far the most abundantly exposed rock in the Meers Valley. They are grayish-white to grayish-pink in color. Bedding is usually evident in this facies. Well-defined incised channel lenses, bars, and sheet-like beds are common.

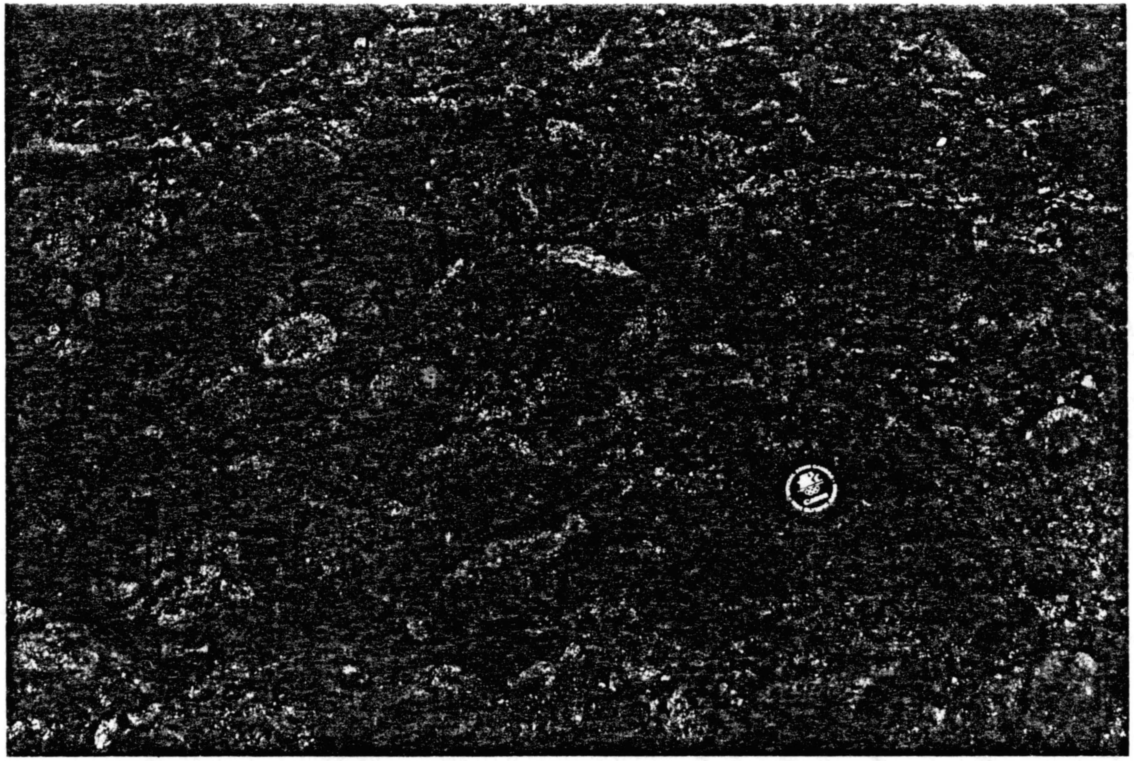


Figure 15. Weathered Granite-clast Conglomerate in a Stream Cut, Granite Clasts are Difficult to Distinguish From Sand and Mud Matrix

Figure 16. Granite-clast Conglomerate in a Road Cut, Rounding of Granite Clasts is Due to "In Situ" Weathering of Wichita Granite Formation Before Deposition of the Conglomerate

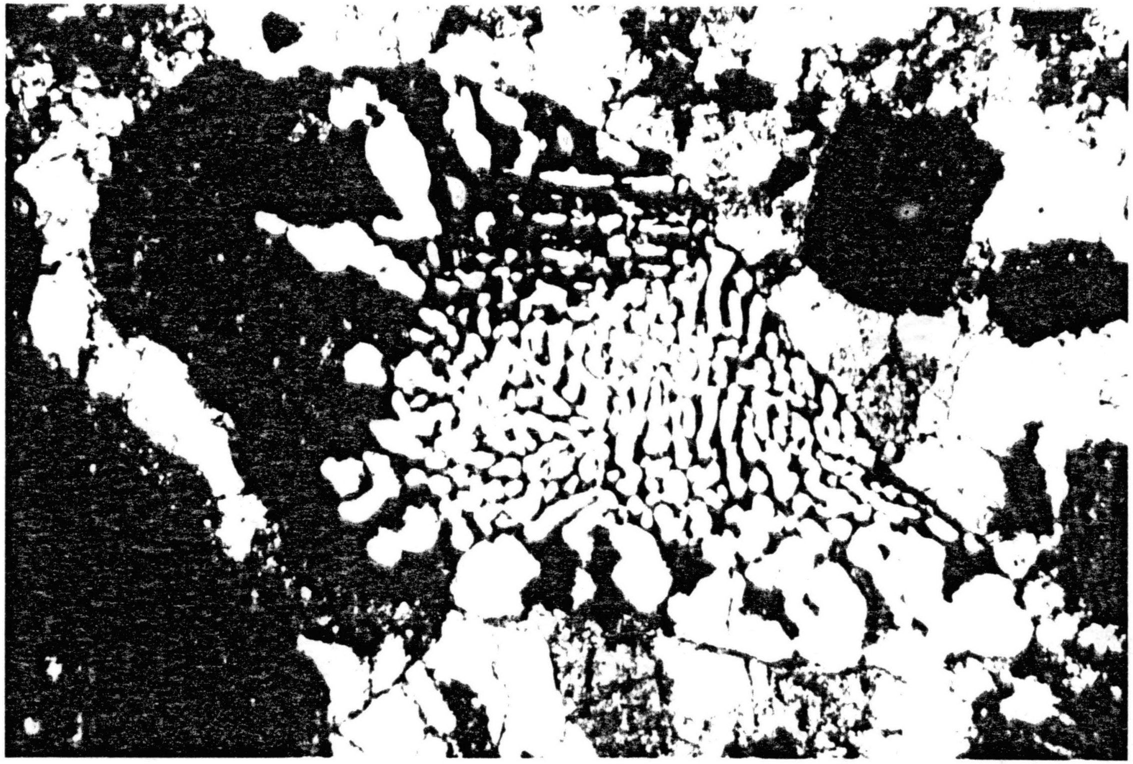


Figure 17. Granophyric Granite Clast in Sandstone From Lake Lawtonka, Cement is Sparry Calcite

The limestone-clast conglomerate can be classified as an orthoconglomerate with an open framework; there is usually very little matrix (under 15%). The clasts are moderately sorted in most outcrops and generally range from 5 to 25 centimeters in diameter. They are subangular to subrounded (Figure 18).

The conglomerate is well cemented with fibrous or sparry calcite or with calcrete. Some late barite and pyrite are present and a few of the larger pores are still open. Calcite cementation occurs mostly as a cavity filling cement and crystals of fibrous calcite occur up to 10 centimeters in length. Due to extensive cementation there is little permeability.

The limestone clasts contain fossils which are similar to those found in the limestones of the Slick Hills. As the Slick Hills form the northern margin of the Meers Valley this is not surprising.

Limestone Megabreccia Horizons

There are three clearly defined limestone conglomerate strata in the northwestern part of the Meers Valley. The lower and upper strata are pebble conglomerates (of the type described in the preceding section) while the middle stratum consists of limestone boulders, some up to 15 meters in diameter, most from 1 to 5 meters across (Figures 19, 20,and 21).

This facies has been termed the "limestone

Figure 18. Coarse Limestone-clast Conglomerate Facies Overlain by More Typical Limestone-clast Conglomerates

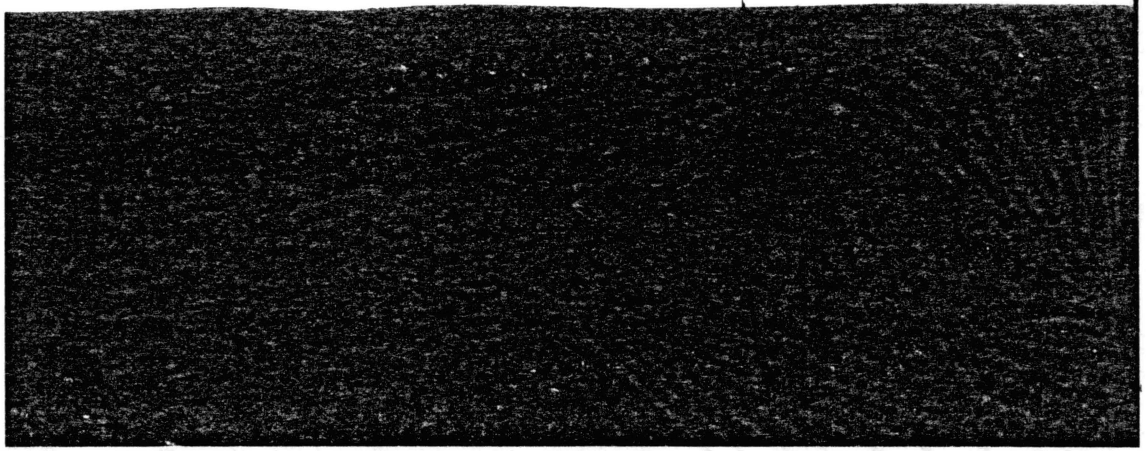


Figure 19. Limestone Megabreccia Deposit Overlying Limestone-clast Conglomerates

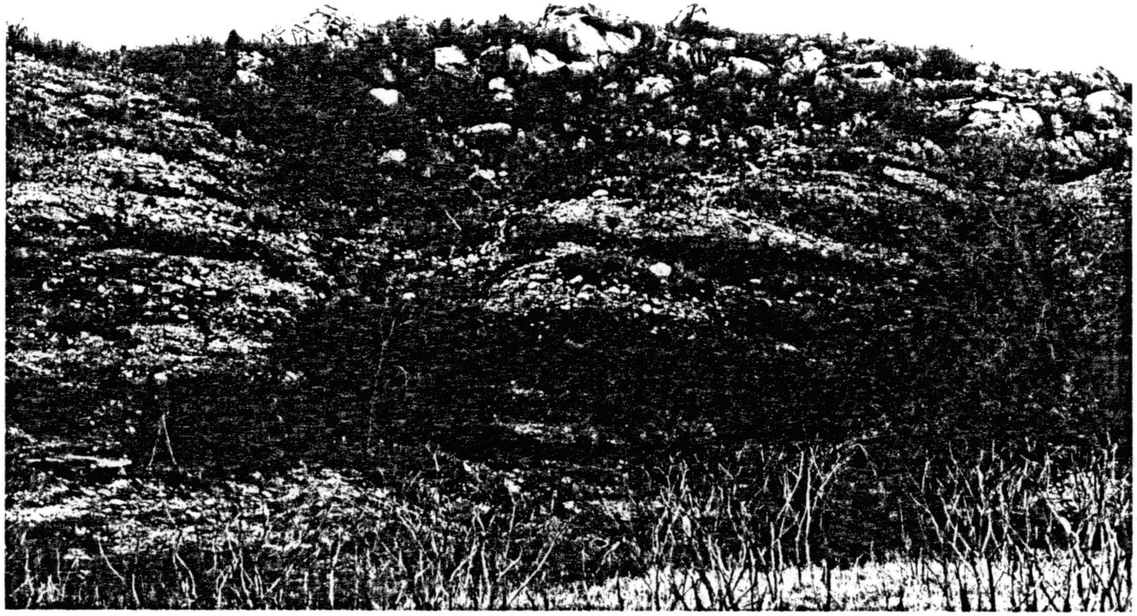


Figure 20. Close View of Megabreccia Deposit Overlying Limestone-Clast Conglomerates, Largest Boulder is Approximately 1 1/2 Meters in Diameter

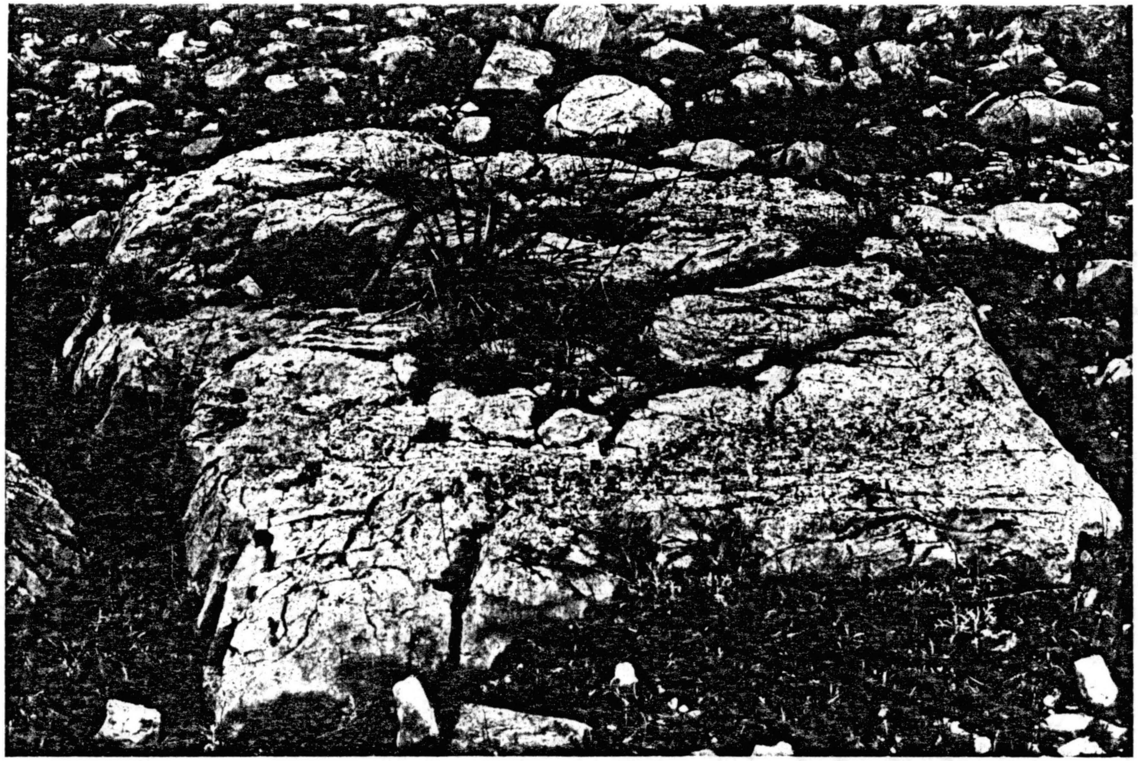


Figure 21. Close View of Individual Megabreccia Clast, Geologic Hammer for Scale

megabreccia" (Donovan et.al., 1985). Originally the enormous limestone boulders were mapped as Arbuckle Limestone outcrop (Miser, 1954). However the stratigraphic relationships are clearly exposed in Jimmy Creek and upon close inspection of the boulders, remnant cement and matrix were seen to coat the boulders. The boulder conglomerate has the same characteristics as the limestone pebble conglomerate; i.e. it is grayish in color, contains angular to subangular clasts and is cemented by calcite or calcrete.

Dolomite Zones. Large dolomite blocks occur throughout the limestone megabreccia horizons in the Meers Valley. Some of these blocks are of Kindblade Formation origin. They consist of dark brown, iron rich dolomite. Isolated blocks are up to 3 meters in diameter, however zones of concentrated dolomite blocks occur up to 4 meters in width and 25 meters in length. Such zones appear linear as if they are parallel with bedding planes. Many dolomite blocks consist of shattered, angular dolomite fragments from 1 to 8 centimeters in diameter set in a "matrix" of smaller fragments and dolosparite cement (Figure 22).

Granite/Limestone-clast Conglomerates

This "hybrid" conglomerate only occurs in the southeastern portion of the Meers Valley. It is characterized by variable percentages of both limestone and granite clasts. The rock is well cemented with calcite (or

Figure 22. Dolomitized Fault Breccia

may be calcreted). In addition much siliciclastic matrix is present. The granite clasts are subrounded while the limestone clasts are more angular. Clasts range from 1 to 15 centimeters in diameter (Figure 23).

Sandstones

Very poorly sorted arkosic sandstones are most common in the southeastern Meers Valley (Figure 24). Erratic pebbles of granite and limestone up to 7 or 8 centimeters in diameter occur in some sandstones. Grains are angular to subangular. Rock color varies and may be buff, orange, maroon, or green.

Most sandstones are cemented by sparry or fibrous calcite; some are hosts to calcretes. Such carbonate-cemented rocks are generally nonfriable. Hematite and barite are more minor cements in the sandstones. In some areas (adjacent tc the Meers and Blue Creek Canyon Faults) zones affected by water and hydrocarbon migration are present. Such migration has leached the rock, removing all cement and in consequence the sandstone are very friable.

Shales

Shales in the northwestern part of the Meers Valley are usually thinly interbedded with conglomerates, however thick units of shale occur. Shales are more thickly interbedded with sandstones in the southern part (Figure 24). The shales are most often maroon to green to buff in

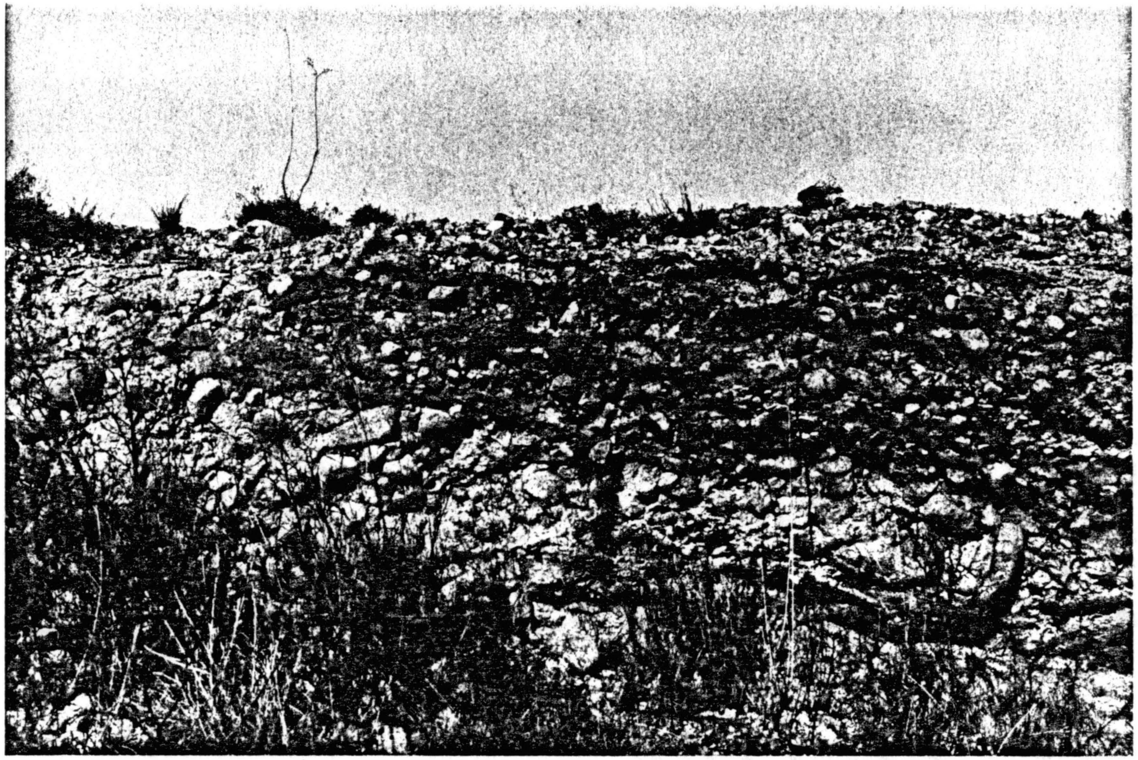


Figure 23. Granite/limestone-clast (hybrid) Conglomerate From Lake Lawtonka

Figure 24. Sandstone Channel and Shale Sequence From the Southeastern Portion of the Meers Valley

color. The shales often host calcrete horizons. Thick deposits in the southeastern part of the valley may represent floodplain and overbank deposits of an alluvial system. Where thinly interbedded with conglomerates, the shales may represent soil horizons.

CHAPTER IV

DIAGENISIS OF THE PERMIAN ROCKS IN THE MEERS VALLEY

Major postdepositional events affecting the Permian rocks in the Meers Valley include several phases of cementation and hydrocarbon migration.

Cementation

Most Permian rocks in the Meers Valley are cemented with various forms of calcium carbonate. Calcium carbonate cement textures in the limestone- and granite/limestone-clast conglomerates and sandstones include anhedral spar, fibrous, poikilitic, pendant, and calcretes. With the exception of calcretes, these cements generally occur as passive, cavity-filling cements in a very porous system.

Hematite, barite, pyrite, and clays are minor cements. Hematite was generally early while barite and pyrite were late cements. Cementation of the limestone-clast conglomerates began almost immediately after deposition, whereas the granite-clast conglomerates still appear relatively uncemented (although they contain some clay matrix).

Calcretes

Calcretes are ancient accumulations of authigenic carbonates which formed in soil horizons; caliche is the most commonly used name for recent equivalents. However, several terms have been put forth in the literature to describe this type of carbonate accumulation. Cornstone, race, duricrust, paleosol, kunkar, nari, kafkalla, and croute are a few examples (Reeves, 1970).

Factors which play a determining role in calcrete development include carbonate supply, temperature, rainfall, geomorphic stability, erosion, sedimentation rate, and time. Above all there must be a carbonate source. It is generally believed that carbonate loess is the source for most calcretes (Leeder, 1975) although carbonate-rich sands will supply enough carbonate for thick calcrete formation (Reeves, 1970). In addition some calcretes are partially cemented by non-pedogenic carbonate. Calcretes form in a semi-arid environment in which precipitation ranges from 10 to 60 centimeters (Steel, 1974). Too little water does not carry carbonates into the subsoil whereas too much causes leaching of the carbonate. The temperature must be sufficient to evaporate subsurface moisture. Hotter temperatures cause more carbonate precipitation (Reeves, 1970). Calcrete development is enhanced by geomorphic stability with long periods of nondeposition between sporadic sedimentation and little erosion. Sedimentation and the rate of subsidence must be minimal if thick calcretes are to form, otherwise the soil profile will be buried too rapidly. Erosion must also be minimal otherwise calcrete horizons will be destroyed.

Ideal locations with suitable conditions for calcrete development include stable segments of alluvial fans and more commonly, floodplains and braided stream channels adjacent to alluvial fans.

Modern caliche formation begins when $CaCO_3$ is dissolved by carbonic acid in rain water and carried into the soil horizon, as represented by the equation:

$$\underset{\text{calcite}}{CaCO_3} + \underset{\text{carbonic acid}}{2H_2CO_3} \quad \underset{\text{calcium bicarbonate}}{Ca(HCO_3)_2} + \underset{\text{water}}{H_2O} + \underset{\text{carbon dioxide}}{CO_2}$$

Calcite is then reprecipitated in the soil horizon during dry periods. Carbonate is first deposited about 2 feet from the surface, in free interstices and then as drainage becomes plugged, intense carbonate impregnation occurs (Steel, 1974). With time and further saturation this plugged horizon extends upward toward the ground surface. Massive laminar calcrete horizons are formed as carbonate saturated is ponded above the plugged horizon and then evaporated (Steel, 1974).

As the calcrete plugs the soil horizon, less oxygen becomes available to the sediments below. In outcrop, reduced sediments are common below mature calcrete horizons.

Successive stages in calcrete formation have been identified by various authors. Tables I, II, III give the stages as listed by the most-quoted authors. Reeves (1970) designates these stages as young, mature, late mature and old age. This nomenclature is followed in this thesis. Tables IV and V give the time required for these stages to develop and the average thicknesses for each profile (Leeder, 1975).

Calcrete is characteristically chalky white although light brown is common and some red and black calcretes have been documented (Esteban, 1976). In thin section calcrete texture is dominantly micritic. Several generations of spar-filled veins may cut this micrite. These veins represent shrinkage of the micrite due to desiccation during exceptionally arid periods. Sparry calcite infilled the cracks at a later date as a drusy cement.

Also, seen in thin section is the replacive and/or displacive nature of calcrete development. Micrite replacing the host rock is evidenced by corroded edges to quartz and other grains. Detrital grains may be brecciated or split by displacive calcrete. Watts (1978) considered that this is due to an excess amount of $CaCO_3$. He noted that some calcretes contain 2.5 times the amount of $CaCO_3$ needed to fill original void space of normally packed sediment. The excess of $CaCO_3$ must either expand the original volume of the host rock or destroy the host material.

TABLE I

PROGRESSIVE STAGES OF CALCRETE DEVELOPMENT IN NONGRAVELLY SEDIMENTS ACCORDING TO GILE, (1970)

Stage 1 -	Scattered grain coatings or carbonate filaments.
Stage 2 -	Carbonate nodules separated by low carbonate material.
Stage 3 -	Carbonate impregnated throughout and plugged in last part of this stage.
Stage 4 -	Indurated laminar horizon, consisting primarily of carbonate, formed on top of plugged horizon.

TABLE II

PROGRESSIVE STAGES OF CALCRETE DEVELOPMENT IN GRAVELLY SEDIMENTS ACCORDING TO GILE, (1970)

Stage 1 -	Horizons have thin, partial or complete carbonate coatings on pebbles.
Stage 2 -	Thicker carbonate coatings and some filaments in interstices between coatings.
Stage 3 -	Horizons have carbonate virtually *throughout, the horizon becomes plugged with carbonate in last part of the stage.
Stage 4 -	Laminar horizon has formed on top of plugged horizon.

TABLE III

PROGRESSIVE STAGES OF CALCRETE DEVELOPMENT
ACCORDING TO STEEL, (1970)

Stage 1 -	Small (1 to 6 cm in diameter), irregularly shaped nodules composing less than 10% of rock.
Stage 2 -	Nodules are up to 10 cm in diameter of vertically elongate and up to 15 cm long. Nodules occupy less than 50% of rock in upper part of profile, downgrading to stage 1.
Stage 3 -	Carbonate appears as nodules, vertical pipes or horizontal sheets. Carbonate occupies more than 50 % of rock but clastic sediment can still be clearly seen within carbonate framework. There is a downward gradation into stage 2.
Stage 4 -	Calcrete exists as beds within which only rare patches of clastic sediment are seen. There is a downward gradation to stage 3.
Stage 4a-	Characterized by distinct horizons of laminar, brecciated or pisolitic carbonate, usually as a capping to stage 4. In some cases carbonate is partially silicified or thin beds of carbonate alternate with thin beds of chert.

TABLE IV

DEVELOPMENT TIME REQUIRED OF STAGES, ACCORDING TO LEEDER, (1975)

Stage 1:	minimum - 1000 years, maximum - 4500 years
Stage 2:	minimum - 3500 years, maximum - 7000 years
Stage 3:	minimum - 6000 years, maximum - 10,000 years
Stage 4:	minimum - 10,000 years

TABLE V

CALCRETE PROFILE THICKNESS OF SELECTED SEQUENCES, COLLECTED AND COMPILED BY LEEDER, (1975)

Stage	Thickness Range	Mean	Samples
1	0.20 - 0.90 m	0.60 m	7
2	0.50 - 2.00 m	1.00 m	5
3	1.00 - 3.00 m	**	2
4	3.00 - 15.00 m	**	15

** - insufficient data because of very large range

Calcretes in the Meers Valley

Calcretes are found throughout the Meers Valley. They are common in the limestone-clast conglomerates and granite/limestone-clast conglomerates as well as in the braided stream complexes and floodplain deposits. The presence of calcrete (as previously discussed) suggests a semi-arid climate at the time of deposition. It also suggests a very slow rate of sediment entrapment coupled with long periods of geomorphological inertia.

The Cambro-Ordovician limestones in the Slick Hills were the most likely source for the abundant $CaCO_3$ needed for calcrete formation. The $CaCO_3$ may have been provided by $CaCO_3$ rich water flowing from the limestone hills into the Meers Valley, from $CaCO_3$ dissolved from the limestone detritus in the valley, or minorly in the form of carbonate loess blown from the Slick Hills and surrounding areas (Figure 25).

Field Appearance. The calcretes in the Meers Valley are white to light buff in color. In the fine-grained rocks, calcrete nodules, glaebules, and rhizoliths occur from 0.5 mm in diameter (in the young stage of development) up to several centimeters in diameter (in more mature stages) (Figure 26). Old age calcrete stages are represented by continuous layers. In the finer rocks cemented with youthful calcretes, the sediment and calcrete nodules separate easily. In more mature stages the

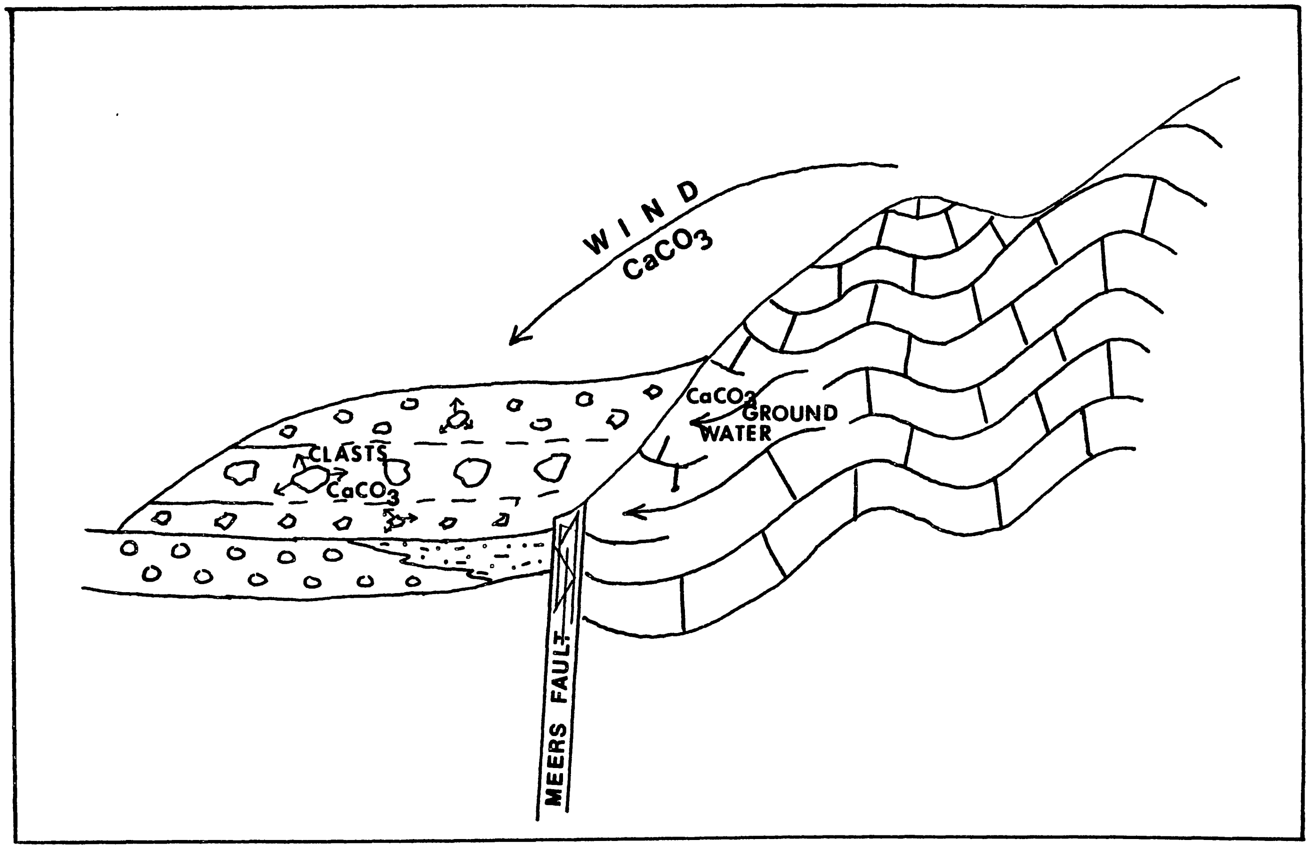


Figure 25. $CaCO_3$ for Carbonate Cements Was Provided by the Cambrian/Ordovician Carbonates of the Slick Hills, Dissolved $CaCO_3$ Was Transported From the Slick Hills by Groundwater, Limestone Dust Was Transported by Wind into the Valley, or Limestone Clasts in Conglomerate Dissolved Providing the $CaCO_3$)

Figure 26. Mature Calcrete Development in Sandstone at Lake Lawtonka, Calcrete Nodules at the Base of the Sequence are Smaller and Less Densely Packed Than at the Top of the Sequence, Thus the Calcrete is in a More Mature Stage at the Top of the Section

sandstone is more firmly cemented and less friable, and in old age stages the rock is very well indurated.

In the limestone-clast conglomerates calcrete development is initiated as coatings on pebbles. In more mature textures, the carbonate filled the voids between the pebbles.

Calcretes in the limestone-clast conglomerates can usually be classified as old age calcretes (Figure 27) whereas calcretes in the finer grained rock are usually less mature. This suggests either that the sedimentation rate on the fans was much less than that in the streams or that reworking of previously deposited material was more common in the stream valleys than in the fans. The latter explanation is perhaps more likely; once cemented the limestone-clast conglomerate would be very difficult to rework.

Old age calcretes in the limestone-clast conglomerates, sandstones, and shales in the Meers Valley range from 5 to 30 centimeters thick. However, late mature calcretes in the finer grained rocks are up to 3 meters thick (Figure 26). These thicknesses for the fine grained rocks are somewhat paradoxial in that they are the reverse of Leeder's (1975) calcrete profile thickness data (Table V). It is suggested that late mature calcretes formed in interfan areas with steady but very slow sedimentation. As a result a relatively thick buildup of calcrete and sediment developed. Old age calcretes formed in interfan

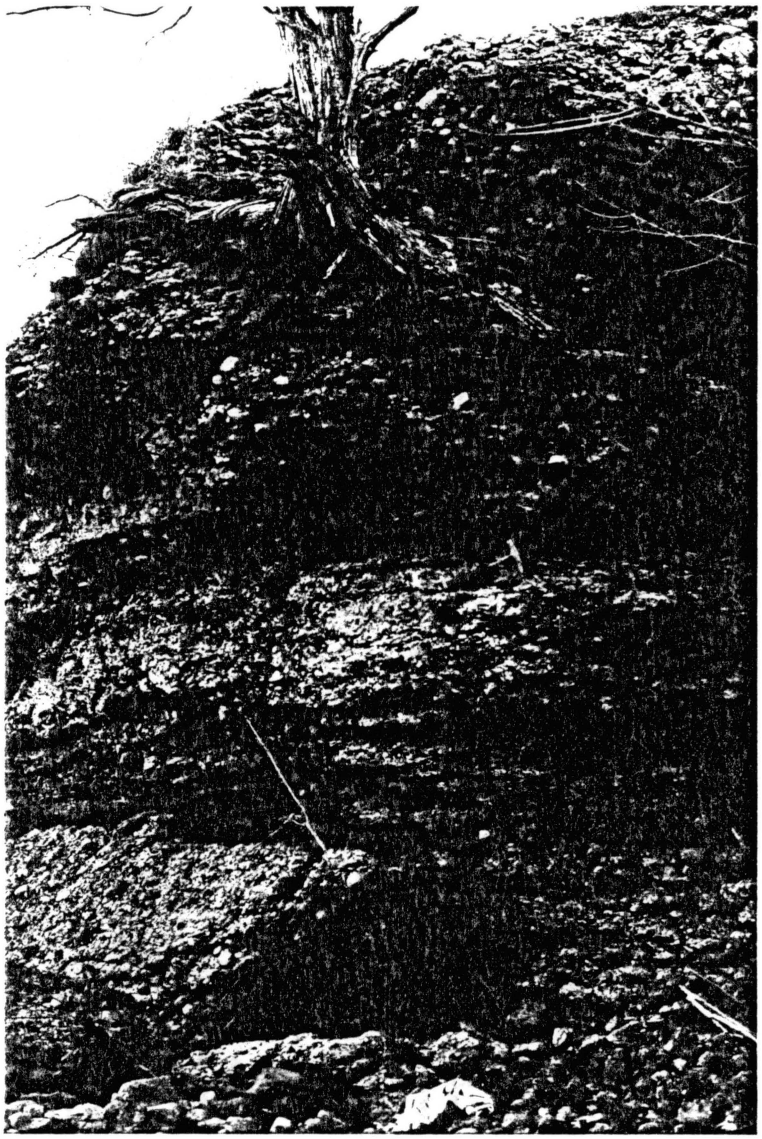


Figure 27. Several Old Age Calcrete Horizons in Limestone-clast Conglomerate, Each is Separated By a Thin Shale Layer and Each Represents a Haiatus in Deposition and Erosion

areas where there was more erratic sedimentation with little deposition for extended periods of time followed by surges in deposition.

Thicknesses of individual youthful calcrete development cannot be accurately measured as small nodules may occur in zones of only a few centimeters, yet these zones occur sporadically throughout a section several meters thick.

Petrography. In thin section the calcrete exhibits classic "textbook" textures. It appears as dense micrite cut by spar-filled shrinkage veins (Figure 28). Several generations of these veins may occur, perhaps representing exceptionally arid periods in the Meers Valley. The sparry calcite infill of the veins suggests that wetter conditions followed such periods. Evidence of replacive and displacive calcretes in the Meers Valley is seen as corroded grains, lack of grain to grain contacts, and the splitting of detrital grains (Figures 29 and 30).

Fibrous Calcite

The limestone-clast conglomerates originally had an open, porous framework (with very little matrix material) through which calcium carbonate-rich vadose waters flowed. Fibrous calcite crystals precipitated from these waters, sometimes completely filling cavities. Such crystals range from microscopic to 10 centimeters in length (Figures 31

Figure 28. Calcrete in Thin Section Appears as Dense Micrite, At Least 2 Sets of Shrinkage Cracks Exist Representing Exceptionally Arid Conditions, Sparry Calcite Fills the Dessication Cracks

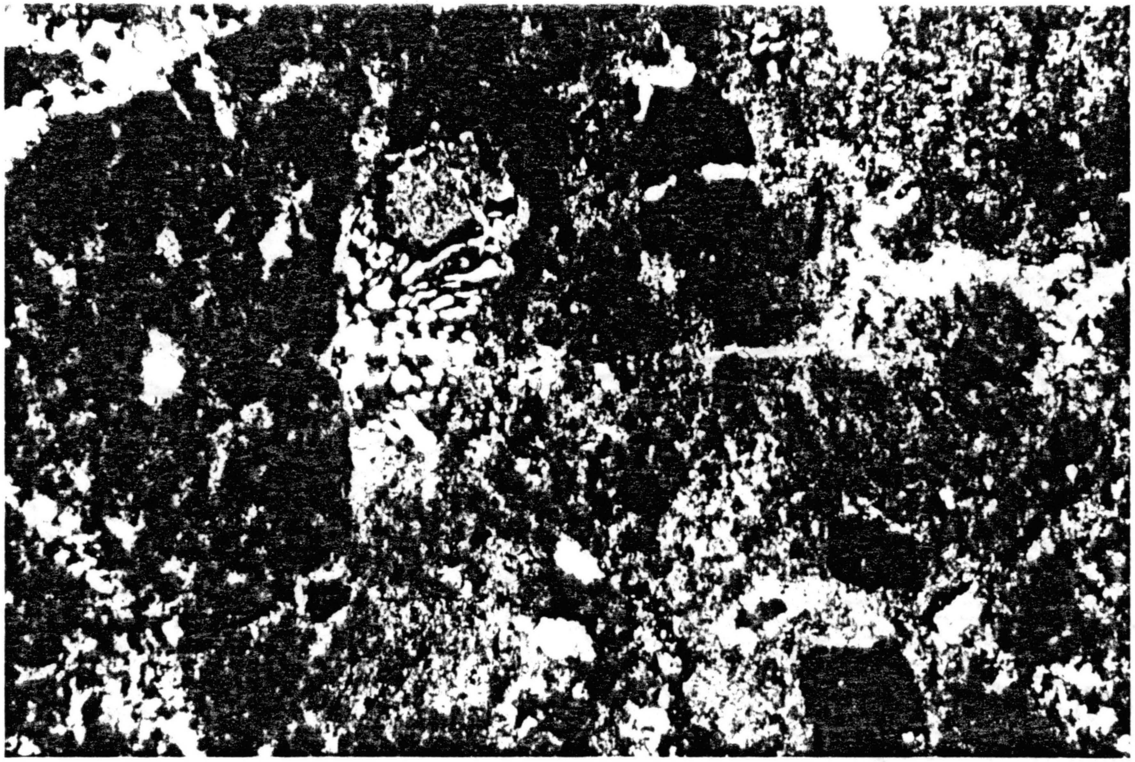


Figure 29. Dislacive Nature of Calcrete is Evidenced by the Lack of Grain-to-Grain Contact in This Mature Calcrete

Figure 30. Mica Lathe is Split by Mature Displacive Calcrete

Figure 31. Fibrous Calcite Radiating Outward From Individual Clasts in the Conglomerate

and 32). The crystals show crystallographic continuity across growth bands (marked by incorporation of hematite into structure). These bands may be due to "seasonal" ground water fluctuations.

As fibrous calcite and calcretes both occur as earliest cements in different parts of the same rock units, it is possible that they formed simultaneously; subsurface fibrous calcite cementation occurred in the porous rock, calcrete cementation formed at the surface of the fan.

Poikilitic Calcite

Poikilitic cementation occurs when a single crystal cements a large number of detrital grains. This texture occurs commonly in clastic sediments when a few carbonate grains act as nuclei for the growth of large (poikilitic) crystals (Scholle, 1978). A few sandstones in the southeastern portion of the Meers Valley underwent poikilitic calcite cementation (Figures 33 and 34). Local ponding of water that was saturated with respect to calcium carbonate, in a quiet environment may produce such a texture.

Anhedral Spar

Anhedral drusy sparite occurs as the latest calcium carbonate cement in the limestone-clast conglomerates and sandstones, filling pores left by earlier cementation. Figure 27 shows hematite filling shrinkage veins in

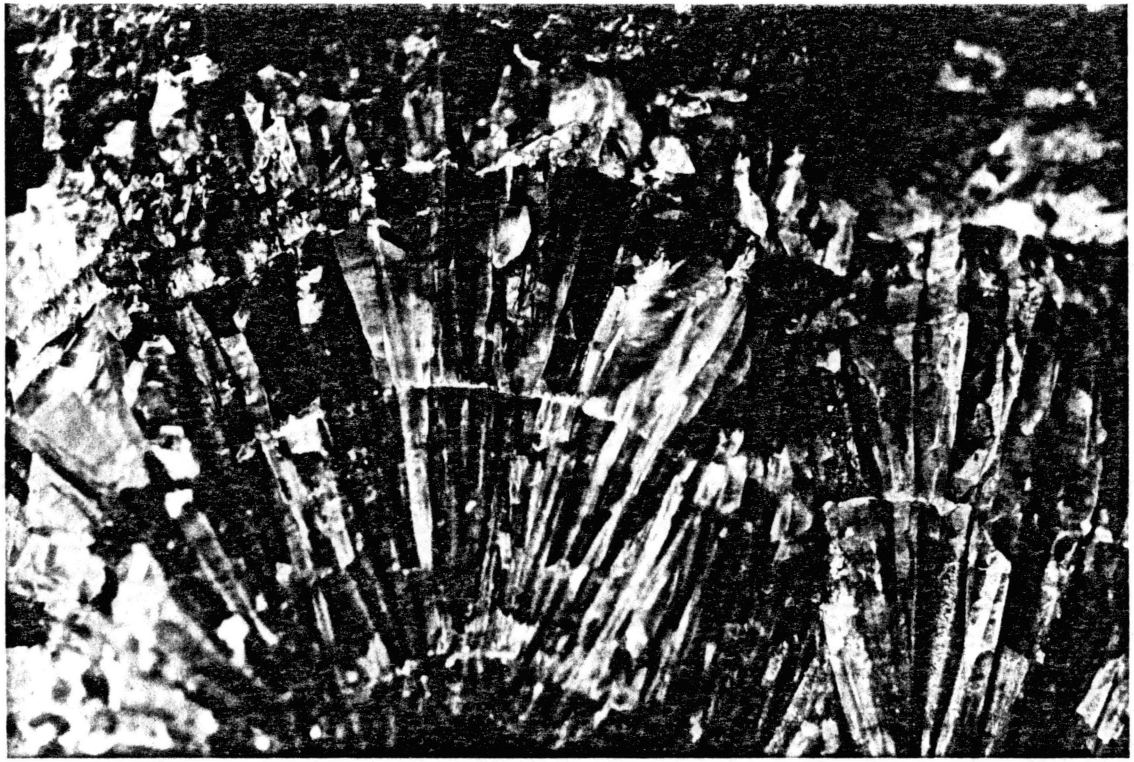


Figure 32. Close View of Fibrous Calcite Shows Continuity of Crystallographic Axes, Growth Bands, and the Incorporation of Hematite into the Crystal Structure

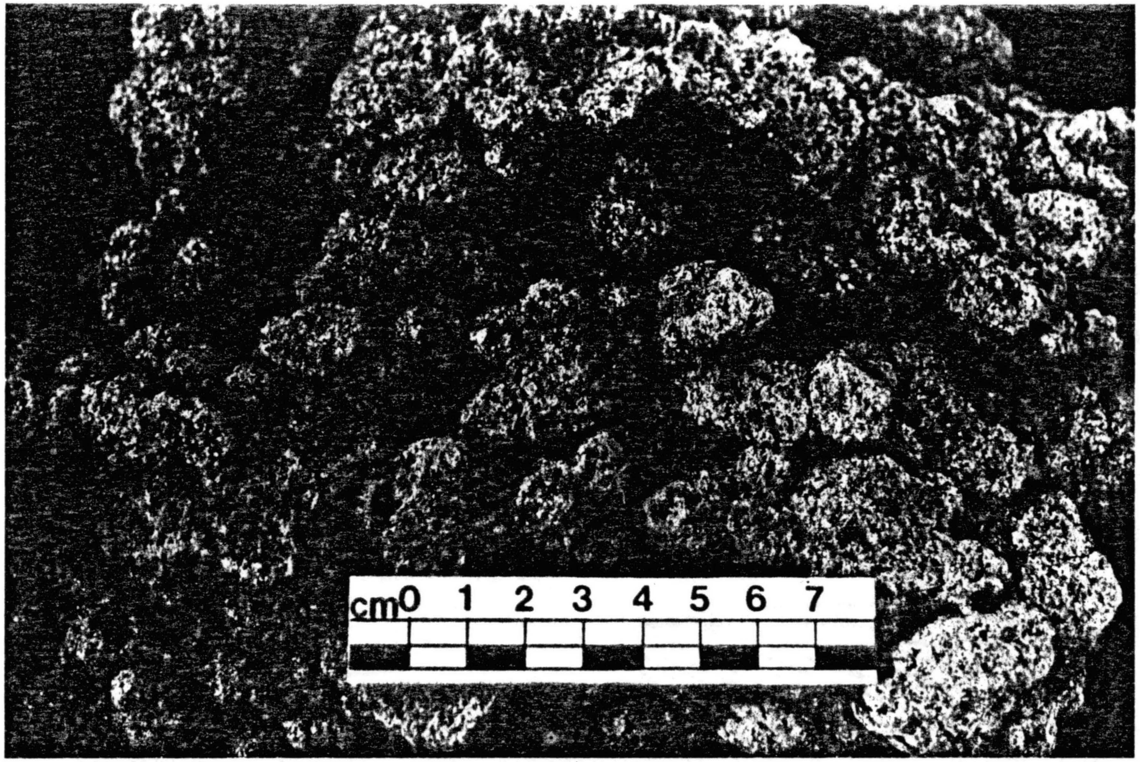


Figure 33. Weathered Sample of Sandstone Which Has Been Cemented by Poikilitic Calcite, Each Nodule is a Single Calcite Crystal Cementing Hundreds of Grains

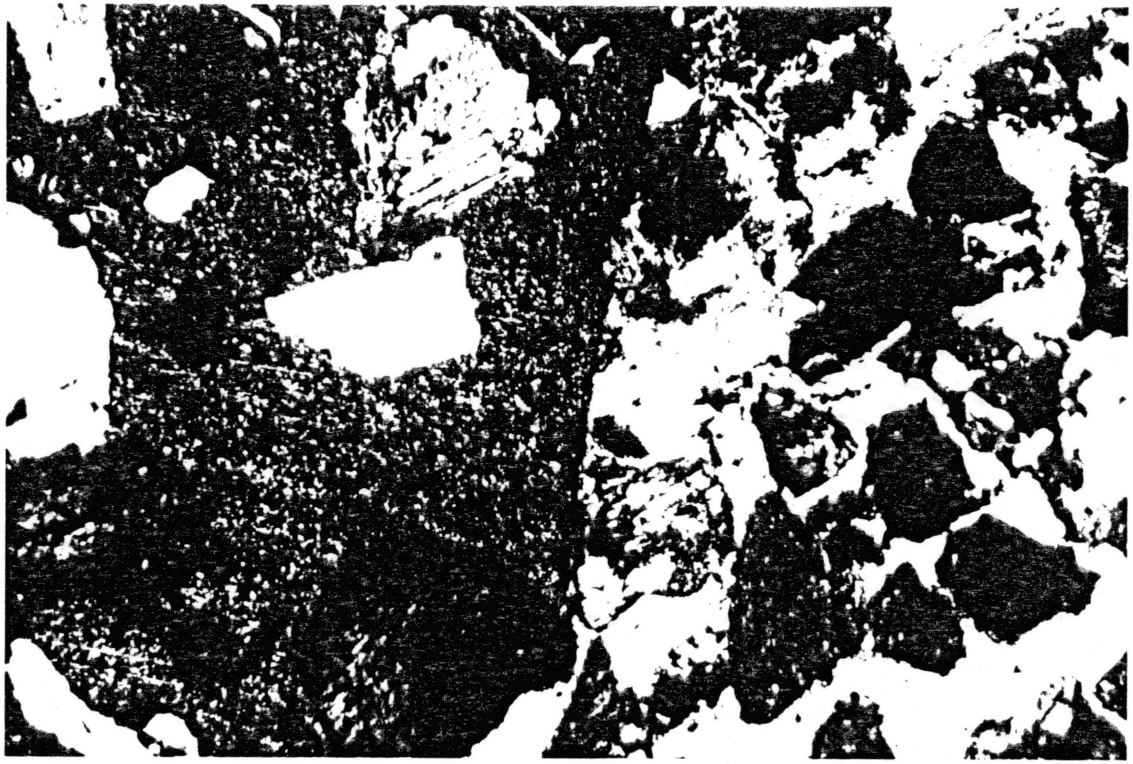


Figure 34. A Photomicrograph of Poikilitic Calcite Cement, Two Calcite Crystals Cement All the Grains, The One on the Left is in Extinction

calcrete. Figure 35 shows hematite predating anhedral spar.

Sparite cementation typically occurs in the phreatic zone or is formed in a deep burial environment (Tucker, 1981). However, no evidence for the latter (i.e. broken fibrous cement fringes) is seen and on general geological evidence (no compaction of clasts or pressure solution are seen) the conglomerates are not believed to have ever been buried very deeply.

Pendant (Dripstone) Texture

This texture is rare in the rocks in the Meers Valley (Figure 36). Dripstone textures indicate that cementation occurred in the vadose zone (Tucker, 1981). Since both pendant and fibrous calcite cements exist, there were probably fluctuations in the ground water table.

Hematite

Hematite is a relatively rare cement in the rocks of the Meers Valley, only occurring where granite derived clasts are present (i.e. granite-clast and granite/limestone-clast conglomerates and sandstones). Hematite cementation occurred both before and after carbonate cementation. This cement is seen to coat the grains in the rock or occur in "blobs" between grains as if ferromagnesian minerals in the rock disintegrated in place (Figure 35).

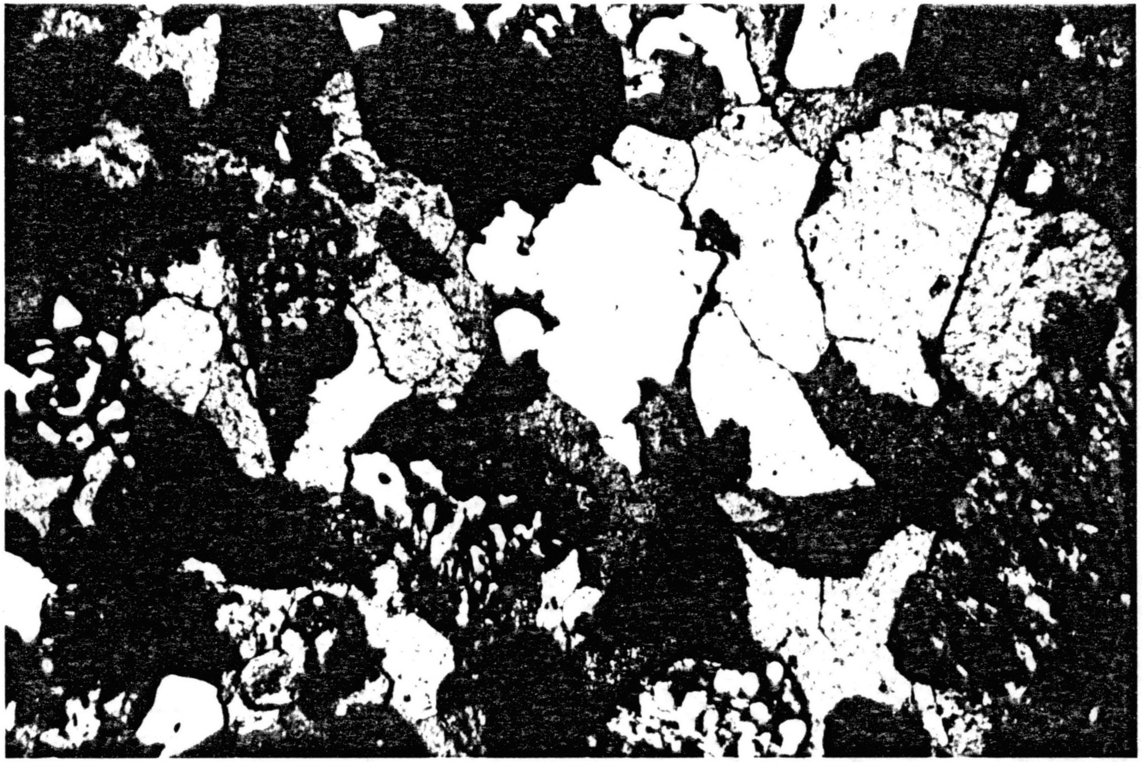


Figure 35. Photomicrograph of a Sandstone Which Was First Cemented by Early Rimming Hematite and Secondly by Late Anhedral Spar

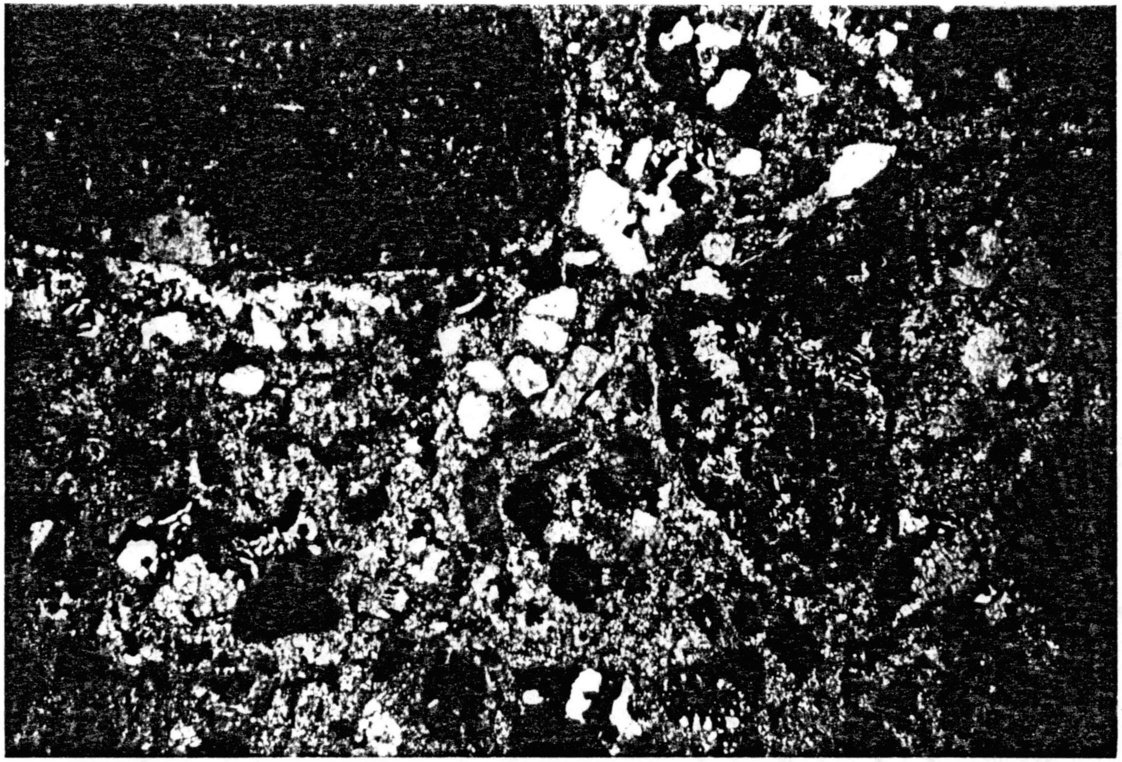


Figure 36. Early Pendant (Dripstone) Cement Formed on the Bottom of a Limestone Clast

Hematite is formed by the oxidation of iron minerals in the rock; hence this phase of cementation was a near-surface phenomenon. It is difficult to recognize the original ferromagnesian minerals in these rocks due to extensive oxidation. However it is possible that some hematite may have been derived from the gabbroic rocks which floor the Meers Valley.

Barite

Barite is a late and uncommon cement in the Permian rocks of The Meers Valley. It is void-filling and euhedral (Figure 37).

Younger et al. (1985) documented an active barite-rich spring north of the Slick Hills. They proposed that the spring results from deep-seated brine waters flowing up through faults and fractures. At present the spring is not precipitating barite (due to the activity of sulphate consuming bacteria). However, the spring has migrated throughout the area and barite tufa and travertine are found in several locations. The age assigned to the barite in this area by Younger et al. (1985) is Pleistocene to Recent.

It is likely that the barite in the Meers Valley is a result of similar processes involving upwardly mobile brines and groundwater; perhaps controlled by fault and fracture patterns. The barite may thus be of Pleistocene or Recent age; however it is probable these processes were

Figure 37. Euhedral Barite Formed in This Calcrete as a Late Cement

occurring in Permian times. As will be noted there is ample evidence of Permian fluid migration through rocks in this area.

Pyrite

Pyrite is also a late and uncommon cement in the Permian rocks of the Meers Valley which may be due to hydrocarbon migration. Cubic crystals of pyrite post-date $CaCO_3$ cement in pore spaces between clasts (Figure 38).

Pyrite forms under reducing conditions where abundant sulfide ions are present. Younger et al. (1985) postulated that brine waters migrated through the area and barite precipitated from these. These brine waters may also be responsible for pyrite formation. Brine waters would provide the sulfide ions and conditions to reduce ferric iron (from weathered ferromagnesian rich igneous rocks) to ferrous iron for pyrite formation.

Clays

Al Shaieb et al. (1980) reviewed clay cementation in the granite-clast conglomerates and sandstones. They suggest that kaolinite is the most common clay and that it is of authigenic origin (based on its delicate crystal form, relatively large size, absence of kaolinite at grain contacts, and sporadic distribution). Some kaolinite has alter relatively large size, absence of kaolinite at grain contacts, and sporadic distribution). Some kaolinite has

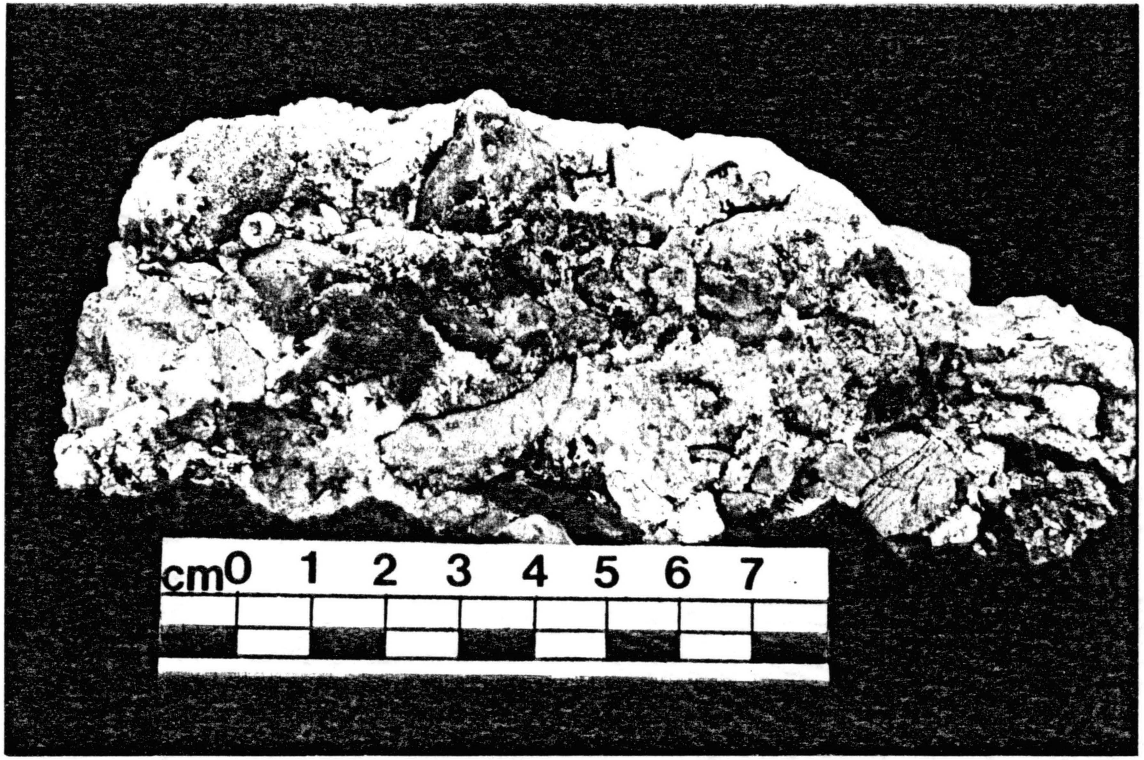


Figure 38. Late Euhedral Pyrite Fills a Cavity in Calcite Cemented Limestone-clast Conglomerate

altered to smectite or illite.

Al Shaieb et al. (1980) noted that chlorite cementation occurred near outcrops of gabbro, which probably provided the iron and magnesium for chlorite formation. This cement occurred as a uniform pore-filling cement which is indicative of allogenic origin (Wilson and Pittman, 1977 from Al Shaieb et al. 1980), but is still considered an authigenic cement (based on the absence of grain-to-grain contacts, and a distinct break in size between the smallest chlorite detrital grains of sandstone and pore-filling clay). Chlorite has also replaced feldspars in the rock. They observed that the chlorite has degraded to a mixed-layer smectite-illite, which in turn altered to kaolinite toward the center of the pores.

Hydrocarbon Migration

Hydrocarbons have migrated though the Permian rocks in the Meers Valley. Bitumens are found in greenish calcrete nodules in sandstones and shales and the rocks are sometimes oil stained. Hydrocarbon is not incorporated into the micritic structure of the calcretes, but occurs in microfractures (Bridges, 1985) (Figure 39).

Hydrocarbons and associated brine waters have reduced the iron in the rocks and leached them of most of their cement.

It is likely that fractures and faults provided an avenue for upward migration (from source rocks). It

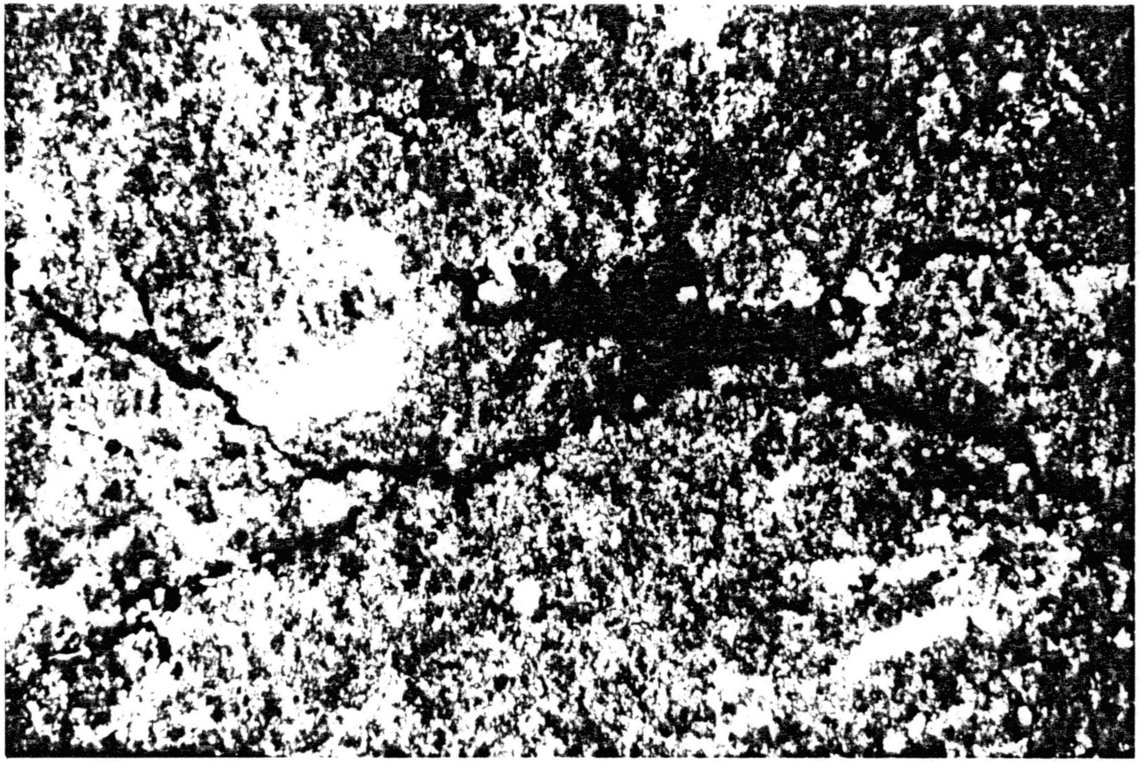


Figure 39. Hydrocarbons in Microfractures of Mature Calcrete

appears that many of the rocks affected by hydrocarbon migration are adjacent to the recently active Meers Fault.

North of the Meers Valley hydrocarbon migration has been incorporated in the structure of Permian $CaCO_3$ travertine, thus dating the timing of the migration, at least in this area (Bridges, 1985).

CHAPTER V

DEPOSITIONAL HISTORY OF THE PERMIAN ROCKS IN THE MEERS VALLEY

Introduction

The rocks in the Meers Valley may be classified as alluvial deposits. The coarse facies were deposited in an alluvial fan environment whereas the finer facies were deposited in a braided stream/floodplain complex. Nielson (1982) lists several characteristic features of alluvial fan deposits. Some features of the Meers Valley deposits collectively suggest a continental depositional environment:

1) Some granite-clast conglomerates have been oxidized and are characteristically red to orange in color.

2) There are few (if any) fossils in the Permian rocks of the Meers Valley.

3) There are few sedimentary structures found in the conglomerates of the Meers Valley.

The presence of closely spaced and numerous calcretes indicate a continental setting as well as a semiarid climate. Many other features are directly indicative of an alluvial fan environment:

1) Depositional bodies often have a lenticular and

wedge-shaped geometry.

2) Fans appear to be radiating outward and in a "downfan" direction.

3) The rocks were deposited close to their source area.

4) The rocks are typically poorly sorted.

5) The granite-clast conglomerates and sandstone facies are compositionally immature.

6) The limestone clasts are poorly rounded reflecting a short distance of transport (granite clasts are rounded due to "in situ" weathering).

7) Some aspects of the deposition can be related to contemporary faulting.

Reading (1978) discussed characteristics of braided streams and flood plains. The following observations are pertinent in his analysis:

1) Sandstone and shale deposits are commonly interbedded with each other in the Meers Valley, suggesting frequent channel avulsion.

2) The sandstone channels show crossbeds and parallel laminations and are often seen to cut into other sandstone channels or shale deposits.

3) Channels are not laterally traceable.

4) Calcrete horizons are common in both sandstones and shales.

5) Shales show laminar bedding and mudcracks.

In general terms it is suggested that the Meers Valley acted as a "perched" basin catching sediments from the Wichita Mountains to the south and the Slick Hills to the north. Most exposures are not of good enough quality to yield accurate paleocurrent readings. However, in some limestone-clast conglomerate and sandstone channels, paleocurrent readings show that alluvial fan channels of limestone-clast conglomerates flowed in a general southwest direction (away from the Slick Hills). In the southeast of the valley, sandstone channels in what is interpreted as a braided stream system, flowed generally to the southeast.

Granite-clast Conglomerates

The granite-clast conglomerates are the oldest exposed Permian rock in the Meers Valley. An outcrop in the NE 1/4, SE 1/4, section 19, T4N, R13W shows granite-clast conglomerates overlain by limestone-clast conglomerates (Figure 40 and 41). The granite-clast conglomerates are composed only of granite clasts (of Mt. Scott type) set in a matrix of arkosic sandstone. A few small chert pebbles are scattered within this conglomerate. The origin of these cherts is unknown; however as there are cherts in the Arbuckle Group, these may be remnant chert fragments that were left on the granite surface prior to erosion of the latter. A clear contact separates the granite-clast conglomerates from the overlying limestone-clast conglomerates. Nowhere were limestone-clast conglomerates seen to be overlain by granite-clast conglomerates, nor is

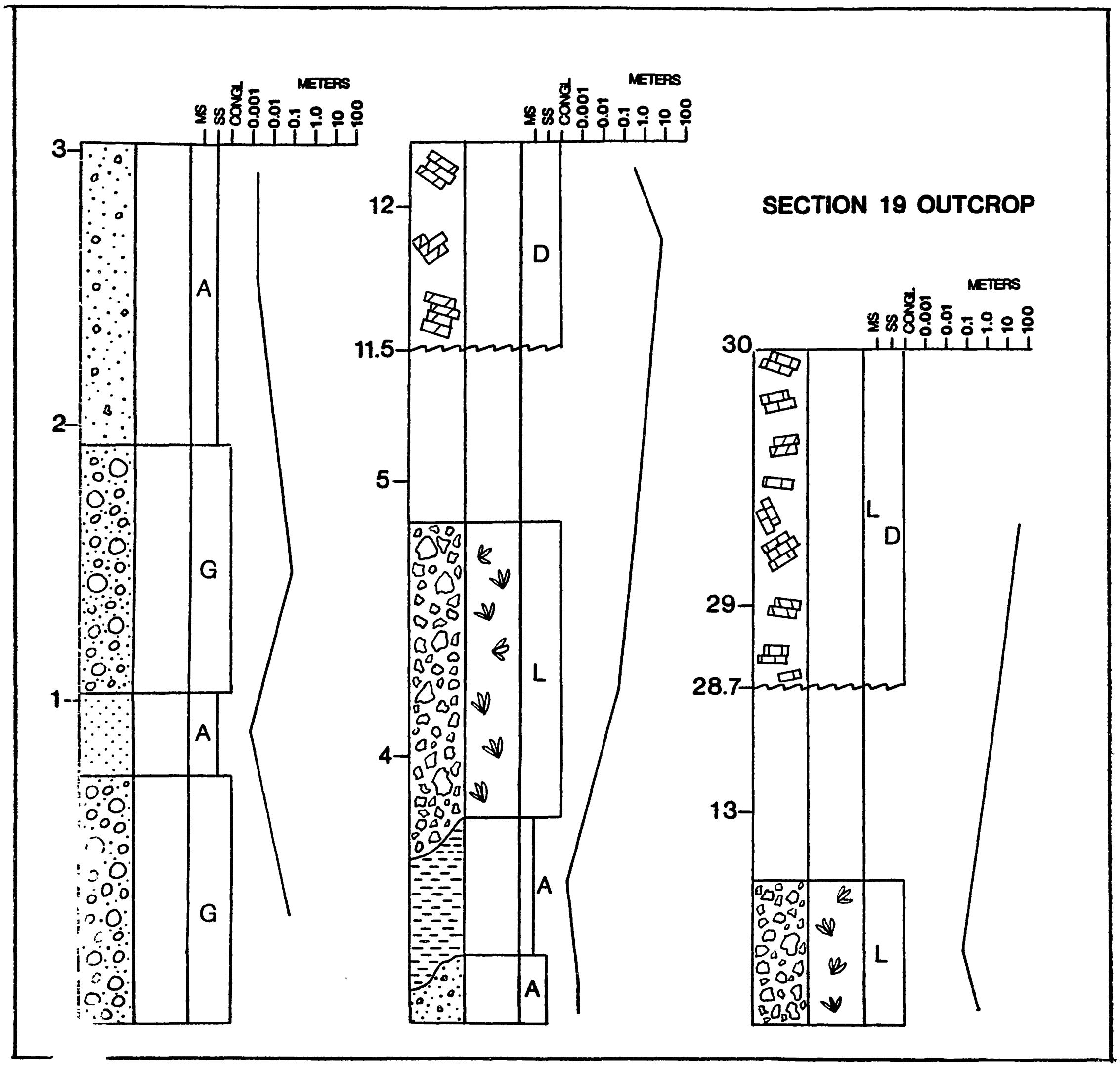


Figure 40. Measured Section in Section 19, T4N, R13W, Granite-clast Conglomerates Interbedded With Arkosic Sandstones are Near the Base of the Outcrop and are Overlain by Limestone-clast Conglomerates and Limestone and Dolomite Megabreccia Deposits, G - Granite-clast Conglomerates, A - Arkosic Sandstones and Shales, L - Limestone-clast Conglomerates and Megabreccia, D - Dolomite Megabreccia,

Figure 41. Photograph of the Section 19 Outcrop, the Road is Approximately the Boundary Between the Granite-clast Conglomerates and the Limestone-clast Conglomerates, Megabreccia Deposits Cap the Hill

there any interfingering of the two types of conglomerates. Other outcrops in section 19 show the same relationship.

The granite-clast conglomerates were deposited after the Wichita Mountain block was uplifted by the ancestral Meers Fault. Alluvial fans transported material from the mountains north into the Anadarko Basin (Figures 42 and 43). This suggestion is based on the existence of Pennsylvanian/Permian granite wash in the Anadarko Basin (possibly a facies equivalent to the granite-clast conglomerates in the Meers Valley) which was derived from the Wichita Mountains.

The ancient Meers Fault became an avenue for erosion and drainage to the southeast. Erosion of the granite into the gabbro accelerated the formation of the Meers Valley. The gabbro weathered easily in comparison with the adjacent limestone block and the limestone block became a local high, trapping the northward bound granite-clast conglomerates in the Meers Valley (Figure 44).

Gilbert (1982) suggested that the granites of the Wichita Mountains weathered in a "tor" fashion. A tor landscape is one that forms in a low-relief area of regularly fractured, homogeneous, igneous materials. In such a setting weathering occurs along the fractures in the subsurface in a water-saturated environment. No erosion occurs. Near the surface the boulders may be completely decomposed. Generally boulders increase in size with depth (Figure 45).

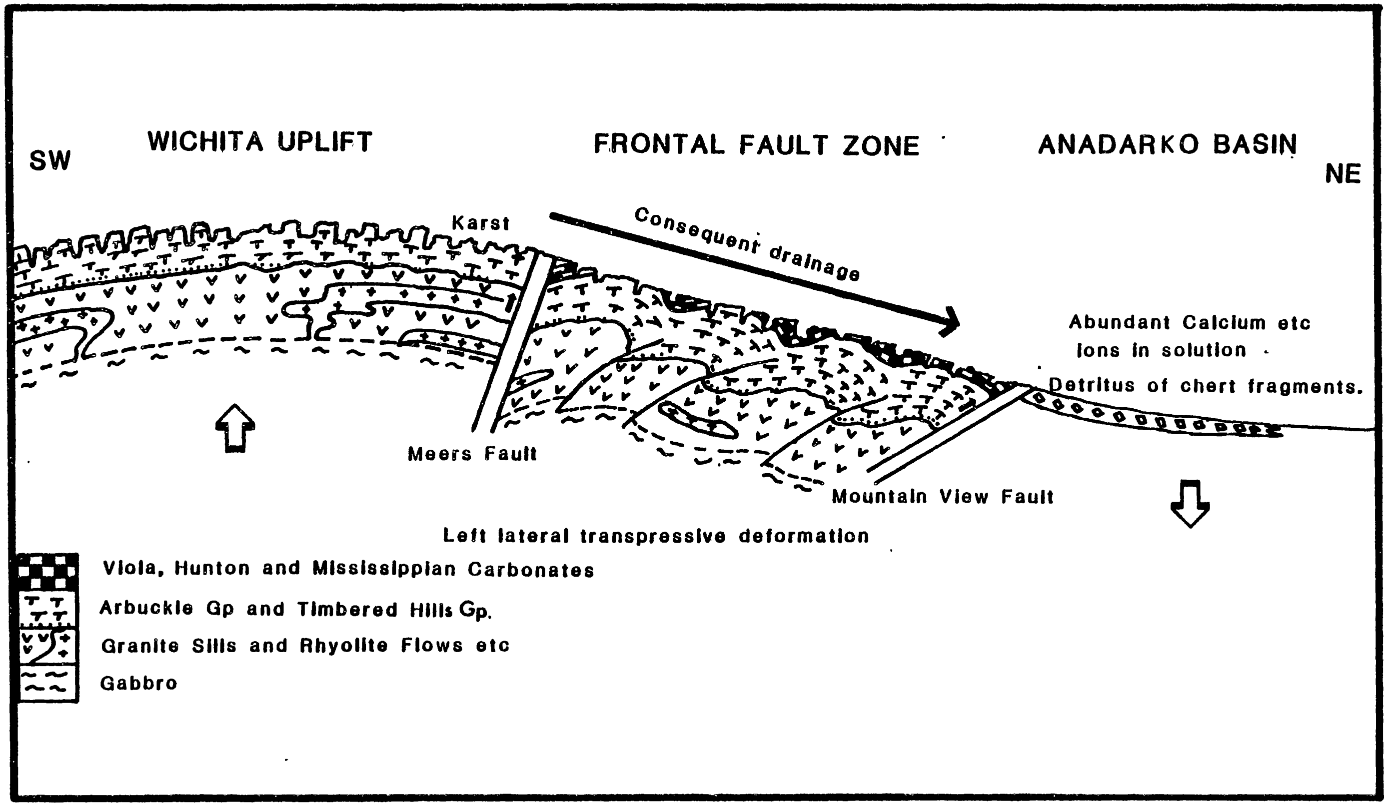


Figure 42. A Late Pennsylvanian Schematic Cross Section of Southern Oklahoma, Karst Weathering Partially Dissolved the Cambro-Ordovician and Younger Carbonate Strata, Some Limestone Detritus Was Transported Northward Into the Anadarko Basin

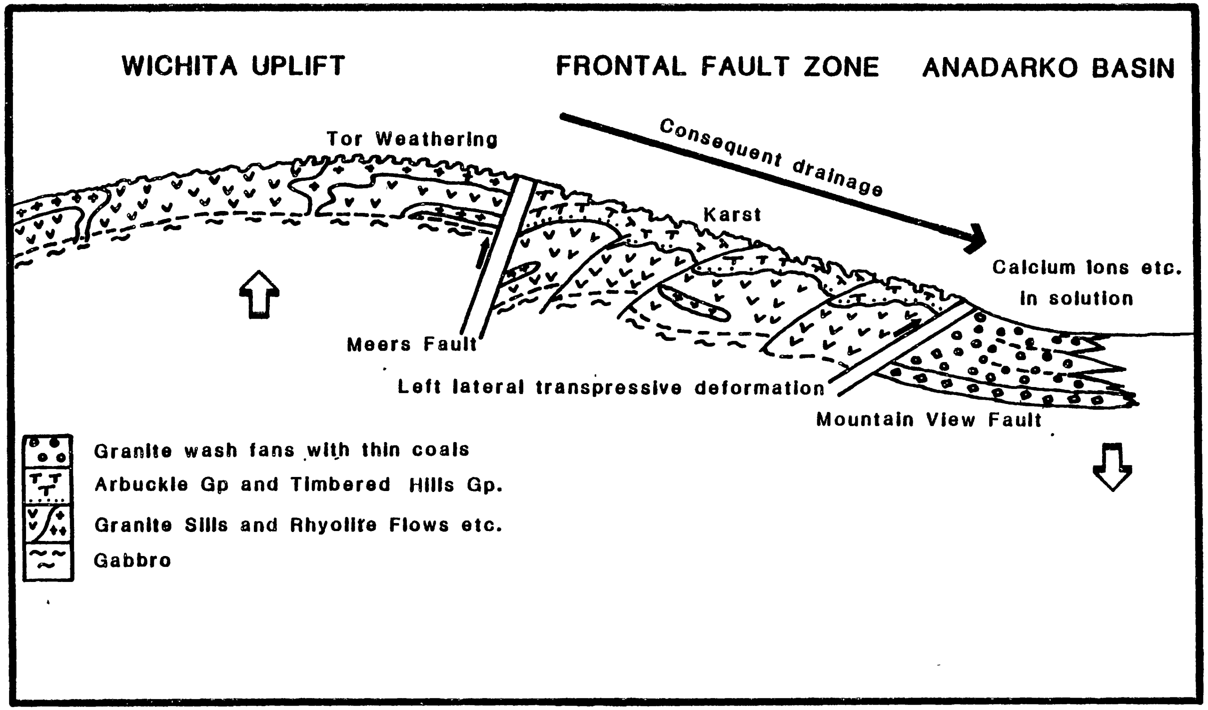


Figure 43. Eventually the Igneous Core of the Wichita Uplift Was Exposed and Igneous Detritus Was Transported Northward into the Anadarko Basin and Deposited as the Late Pennsylvanian Granite Wash

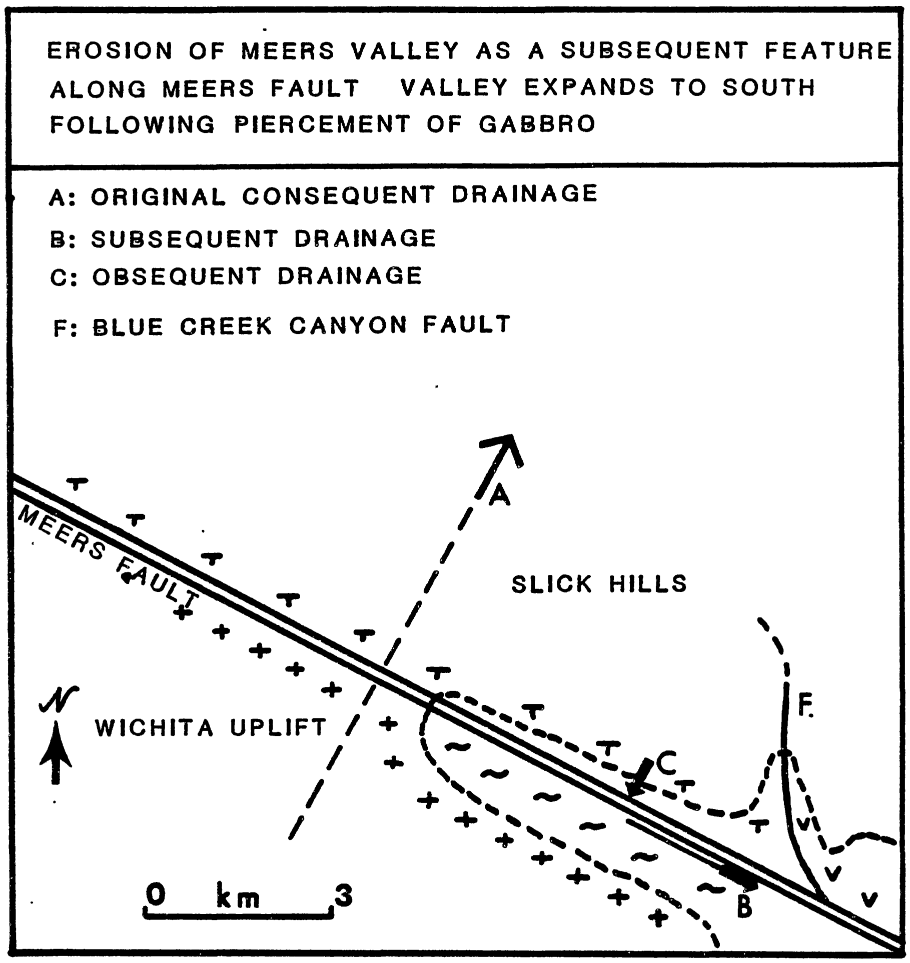


Figure 44. Schematic Plan View of the Meers Valley Area in Late Pennsylvanian Time, Original Drainage Was Northward, the Meers Fault Provided an Avenue For Subsequent Drainage to the Southeast, Following Piercement of the Gabbro the Formation of the Valley Accelerated, Obsequent Drainage to the Southwest Was the Last to Develop

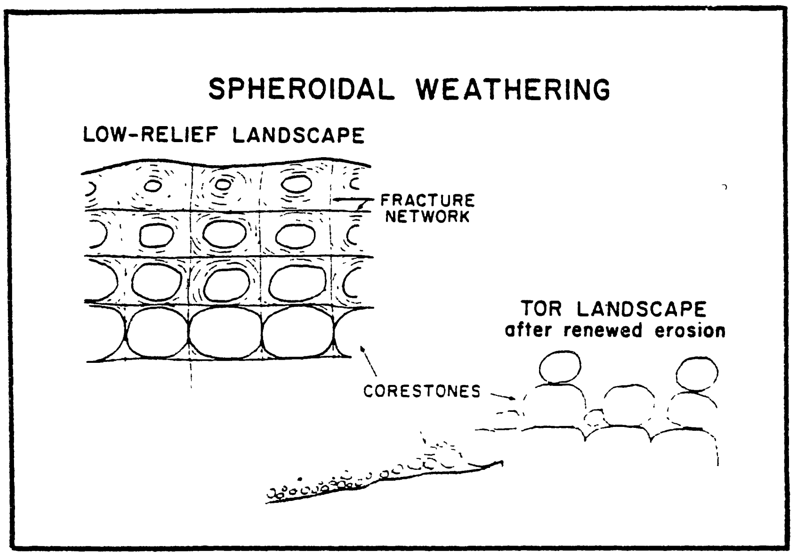


Figure 45. Tor Weathering of Granite in the Wichita Mountains (after Gilbert, 1982)

In the case of the Wichitas, Gilbert (1982) speculated that either after renewed uplift or following increased precipitation, erosion dominated weathering. This erosion stripped the weathered rind off the pebbles, leaving "spheroidal" boulders or pebbles. Thus, the roundness of the granite pebbles in the Meers Valley granite-clast conglomerates is probably due to "in situ" weathering not transport. The residual boulders became either 1) tors (columns of rounded boulders, 2) boulder streams, or 3) conglomerate fill in valleys.

As the Meers Fault has a history of sporadic movement, rejuvenated uplift is a possible cause for the initiation of erosion. However, no calcretes have been found in the granite-clast conglomerates (as they have in higher deposits), suggesting that the climate was not semiarid, but more humid during the time of granite-clast conglomerate deposition. The amount of clay matrix in the granite-clast conglomerates (presumably derived from weathered feldspar) also suggests a more humid climate at the time of deposition.

Most likely both rejuvenated uplift and increased precipitation played a role in initiating erosion of the Wichita Mountains. Both hypotheses support deposition of the granite conglomerates in Late Pennsylvanian time.

1) If tectonics ended in Late Pennsylvanian time (as suggested by Webster, 1980) and granite-clast conglomerates are a direct response to this uplift, then these

conglomerates must be at least in part, Late Pennsylvanian in age, particularly as they underlie the limestone megabreccia deposits (discussed in Chapter II).

2) The Permian climate is interpreted to have been semiarid (see Chapter IV). If the granite-clast conglomerates were deposited in a more humid environment, then an earlier (Pennsylvanian) date is implicit. It is pertinent to note that coal measures are interbedded with the Pennsylvanian Pontotoc granite wash (Donovan, 1985).

The granite-clast conglomerates are poorly stratified, contain few to no sedimentary structures. They are matrix-supported and show no imbrication or consistent pebble orientations and hence offer no flow directions. According to Nielson (1982) these features indicate that the granite-clast conglomerates were deposited as alluvial fan debris flows.

Limestone-clast Conglomerates

Most of the limestone-clast conglomerates were deposited on top of the granite-clast conglomerates. This relationship suggests a reversal of effective stratigraphic displacement along the Meers Fault. The fault uplifted the northern block, exposing the Timbered Hills and Arbuckle Limestones of the Slick Hill. Consequently, alluvial fans shed material from the hills to the southwest into the Meers Valley.

Mature calcretes cement most of the limestone-clast conglomerates in the Meers Valley. This suggests that there was little activity on the fan surfaces between times of deposition.

The limestone-clast conglomerates are composed almost entirely of pebble to boulder size clasts. Little fine matrix appears in the limestone conglomerates. Presumably the finer limestone clasts either dissolved in transport or were blown away as carbonate dust. The absence of matrix together with the size of the clasts (5 to 15 centimeters) suggests that the limestone-clast conglomerates may have been deposited as sieve or talus deposits.

Bull (1972) described sieve deposits as "lobate gravel deposits" derived from an area which supplies little sand, silt, or mud. Such deposits are sufficiently permeable to allow water to infiltrate entirely before reaching the toe of the fan. Hooke (1967) stated that the source area for such deposits is likely to have been jointed (or fractured) and that the resulting clasts are angular rather than well-rounded. Reading (1978) noted that sieve deposits are poorly imbricated and that the clasts are well-sorted. Hooke (1967) also stated that sieve deposits act as a trap for fine materials and eventually become plugged and therefore are not easily recognized in the ancient record. The limestone clasts in the limestone-clast conglomerates of the Meers Valley are angular, poorly imbricated, and well-sorted, and the source area rocks are highly fractured and faulted. The Meers Valley limestone-clast conglomerates may represent ancient sieve deposits, most of which were never plugged because of the lack of fine material.

The oldest limestone-clast conglomerates are relief related rather than tectonic. Due to increasing aridity of the climate in Permian times, the limestone block became increasingly resistant to corrosion, relative to the igneous block. Inverted relief developed; the structural low became the topographic high (Figure 46). As a result relief related alluvial fans began to shed limestone clasts into the resultant valley on top of the granite-clast conglomerate fans (Figure 47).

With rejuvenated and reversed movement along the Meers Fault, the limestone block was uplifted. Possibly earthquakes associated with the movement caused large blocks of limestone and dolomitized fault breccia to tumble or slide into the Meers Valley. These megabreccias were deposited onto both the earlier limestone-clast conglomerates and directly onto the granite-clast conglomerates (Figure 48). This suggests that the first episode of limestone-clast conglomerate deposition was minor and not extensive.

When tectonics ended, a second episode of relief-related limestone-clast conglomerates were deposited (Figure 49). Preserved limestone-clast conglomerate channels in the upper section appear to have drained to the southwest, from the Slick Hills. Conglomerates related to

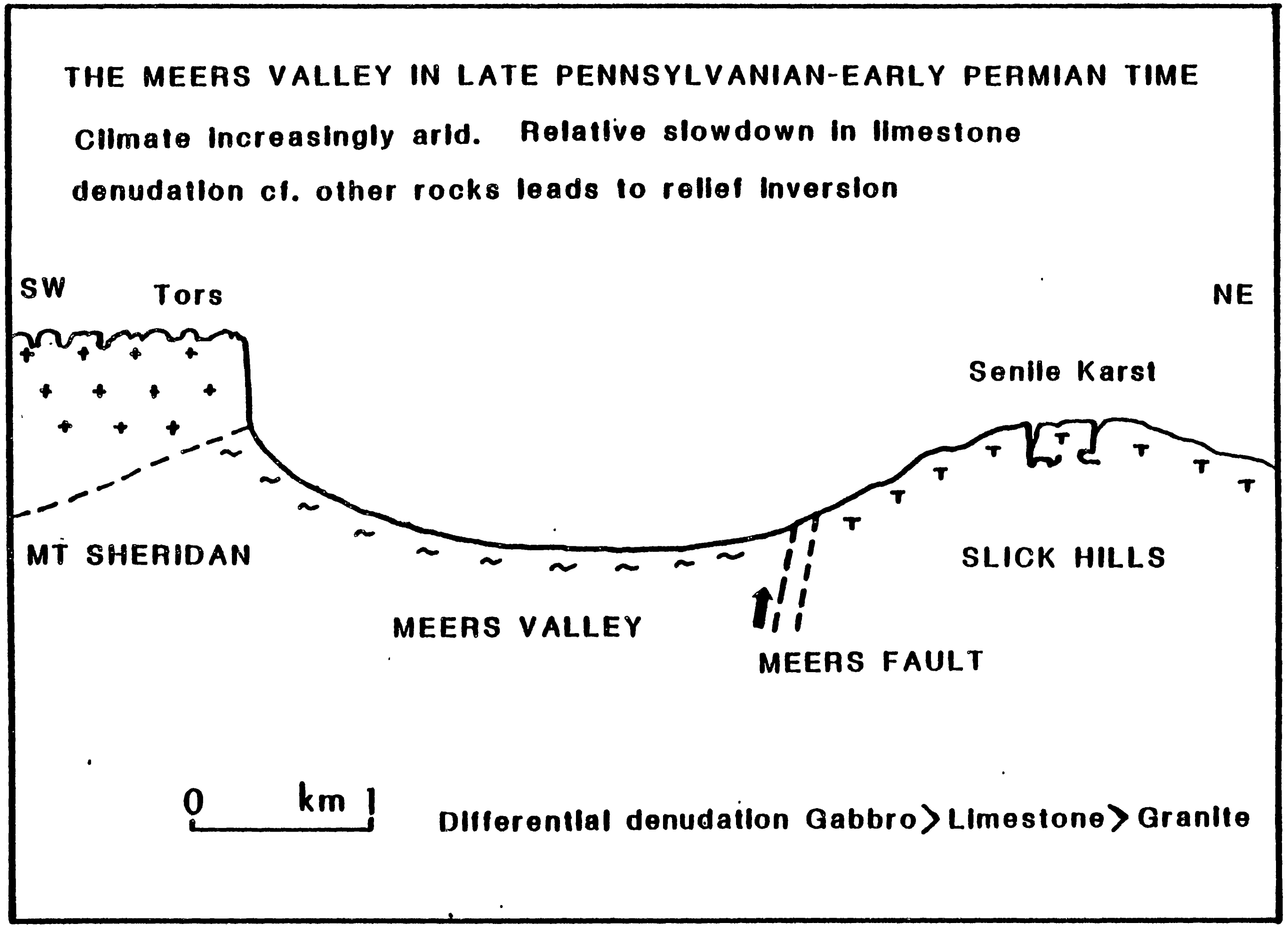


Figure 46. Schematic Cross Section of the Meers Valley in Late Pennsylvanian - Early Permian Time, the Climate Was Becoming Increasingly Arid, Weathering of the Limestone Block Decreased in Comparison With the Igneous Rocks and Inverted Relief Formed - the Structural Low Become the Topographic High

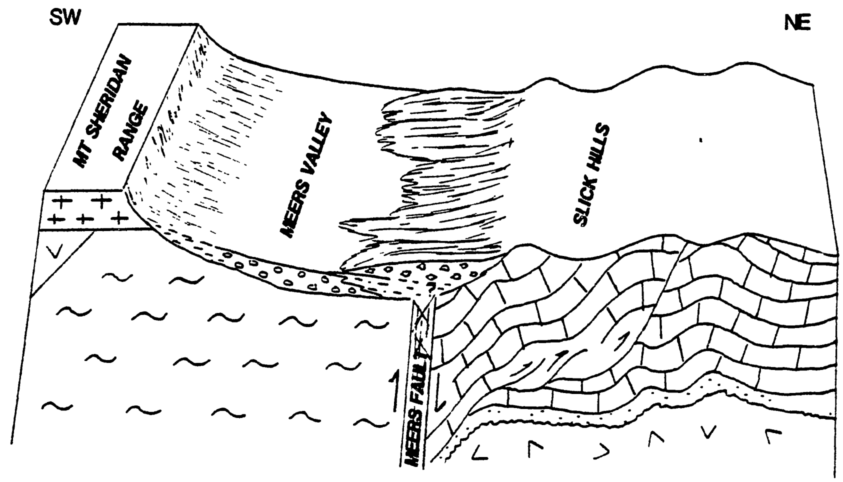


Figure 47. Relief of the Limestone Block Became Sufficient to Support Limestone Detritus for Alluvial Fan Formation in the Meers Valley

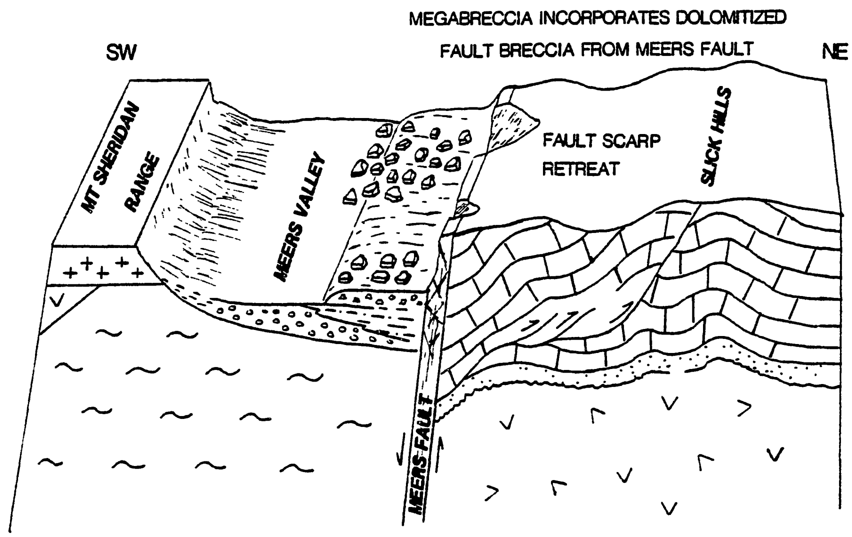


Figure 48. Rejuevenated and Reversed Movement Along the Meers Fault Uplifted the Limestone Block, Possibly Earthquakes Associated With the Movement Caused Boulders of Limestone and Dolomitized Fault Breccia to Tumble Into the Valley Onto Limestone Clast and Granite Clast Fans

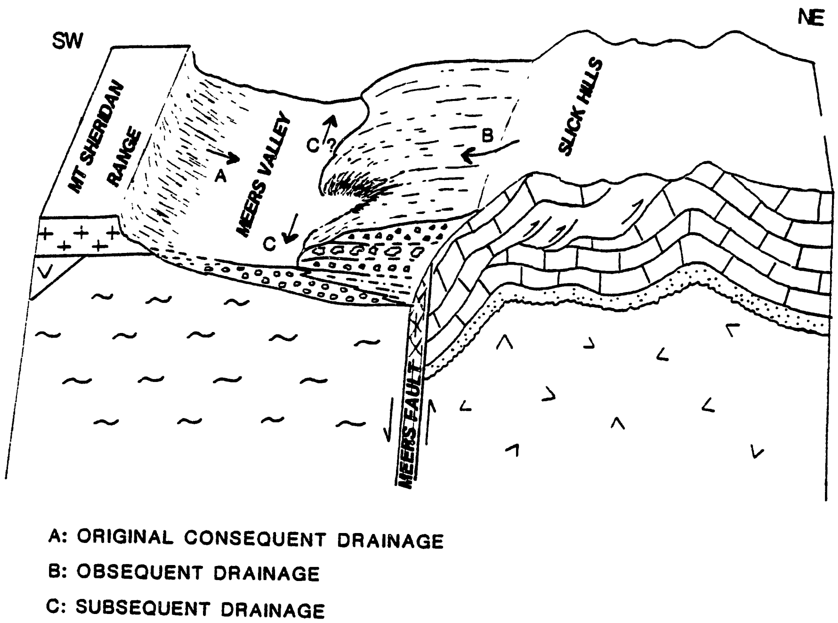


Figure 49. After Tectonics Ended a Second Episode of Limestone-clast Conglomerates Which Were Relief Related Were Deposited

this episode constitute the final preserved veneer over much of the Slick Hills and the Meers Valley.

Megabreccia Horizons

The horizons of limestone and dolomite megabreccias within the limestone-clast conglomerates lie as much as 4 km from the closet outcrop of Arbuckle Limestone. It is difficult to account for transportation of these giant boulders (up to 30 meters in diameter) over this great distance without invoking a catastrophic event. Boulders of this magnitude have been recorded in alluvial fan deposits along active fault scarps. Earthquakes related to fault movement are responsible for the transport of these megaboulders, and it is likely that the megabreccias of the Meers Valley are the result of similar circumstances.

The actual mechanism of transport of these boulders may be one or more of several: rockfall, landslip, boulder train, or air cushion deposits. Evidence to pinpoint any mechanism is scarce but is currently under investigation by Bridges (1985).

Dolomitized fault breccia from the Meers Fault (Figure 48) may be the origin of many of the dolomite megaclasts. However dolomite (and limestone) clasts of Kindblade Formation origin are also present. The nearest outcrop (and hence most likely source) of this formation is over 2 km to the northwest, suggesting left-lateral strike-slip movement along the Meers Fault during and since the deposition of the megabreccia.

As suggested earlier the boulder-breccia deposits of the Meers Valley may have been deposited as early as Late Pennsylvanian time. They record late movements of the Meers Fault which uplifted the Slick Hills to the north. Dating of this movement partially involves a circular argument. Webster (1980) and other authors suggest that tectonism in the Wichitas concluded in Pennsylvanian time. However if they had known of the megabreccias, they may have extended the period of tectonic activity into Early Permian time.

Granite/Limestone-clast Conglomerates

Conglomerates containing granite and limestone clasts occur in the southeastern portion of the Meers Valley. The most likely mechanism for the mixing of the two types of clasts only in this area is erosion and redeposition of the clasts from earlier-formed deposits. In the Meers Valley a topographic axial low existed between the fans debouching from north and south, allowing axial drainage to the southeast. Clearly it is possible that clasts were eroded from the valley slopes (which were formed of earlier fan material) , transported down the valley, and then redeposited.

There are several hypotheses which would account for the southeast drainage: 1) differential weathering of the gabbro created a low to the southeast. This would have involved weathering of exposed gabbro which was not covered by the granite-clast or limestone-clast conglomerate fans, 2)tectonic tilting of the valley to the southeast occurring before the limestone-clast conglomerates were deposited, with granite/limestone-clast conglomerates being deposited in the southeast simultaneously with the limestone conglomerates in the northwest, 3) tectonic tilting of the valley to the southeast and deposition of the granite/ limestone-clast conglomerates after the deposition of the limestone-clast conglomerates.

The simplest solution is the first. Gabbro weathers relatively quickly even in a arid climate. Also, there is no direct evidence of tectonic tilting of the valley as needed to support hypotheses 2 and 3.

Sandstones and Shales

Most sandstone and shales are found in the southeastern portion of the Meers Valley. These were evidently deposited by the same axial fluvial system which transported limestone and granite clasts to the southeast. It is suggested that the sandstones were deposited in channels of a braided stream complex, and that the shales were deposited as floodplain overbank deposits further to the southeast than the "hybrid" conglomerates.

The well-defined sandstone channels are interbedded with sequences of shales suggesting frequent channel avulsion. Such avulsion is a common feature of the braided stream environment (Reading, 1978)

Most of the grains in the sandstones are of plutonic origin. This is probably because the igneous clasts broke down to sand size fragments (whereas many of the limestone clasts dissolved).

The sandstones and shales were deposited under episodic conditions with long periods of nondeposition between sedimentation, as evidenced by the closely spaced and numerous calcretes present (see Chapter IV). Many calcrete horizons have been cut by stream channels. Often reworked calcrete nodules are found incorporated in sandstone channel sediments.

The Significance of the Meers Valley Calcretes: Condensed Sequence

In a discussion of calcretes in the New Red Sandstone (Permo-Triassic) of N.W. Scotland, Steel (1974) compared two calcrete bearing sequences (from the Isle of Rhum and Gruinard Bay), contrasting the number of calcretes in a given thickness of strata (Figure 50). Both sequences occupy the same time interval. However, subsidence at Gruinard Bay was more rapid and the section contains fewer and less mature calcretes per unit thickness. By contrast the Rhum sequence contains a greater total amount of considerably more mature calcretes. Steel (1974) referred to the sequences of the latter type as "condensed sequences".

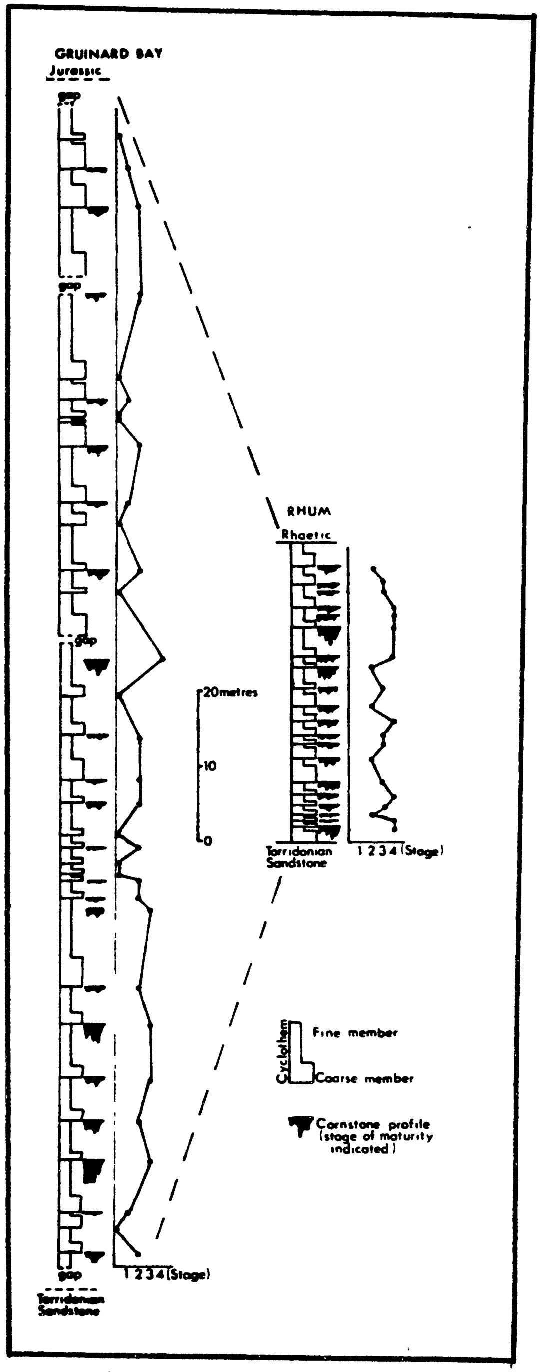


Figure 50. Calcretes in a Thick New Red Sandstone Succession (Gruinard Bay) Compared With a Much Thinner Section (Rhum). Calcrete Profiles are Less Mature and Fewer Per Unit Thickness in the Thicker Section, Emphasizing the Condensed Nature of the Rhum Section (after Steel, 1974)

An analogy can be drawn between the rocks of Rhum and Gruinard Bay and those in the Wichita Mountains area (Meers Valley) and the Anadarko Basin. Meers Valley calcrete sections fit Steel´s description of a condensed calcrete sequence.

Permian deposition in both the Anadarko Basin and the Meers Valley was simultaneous but sediment thicknesses differ considerably). The section in the Meers Valley is incomplete in comparison with that in the Anadarko Basin, and periods of nondeposition are recorded by calcrete horizons. Old age calcretes are often numerous and closely spaced in the Meers Valley (as in the Rhum sequence) but sparse to absent in the Anadarko Basin.

Steel contends that numerous and closely spaced calcretes indicate a stable environment and a slow sedimentation rate. Lower Permian sediments in the Wichita Mountains area are at most 200 meters thick (Chase, 1956) whereas Permian sediments in the Anadarko Basin are as much as 2300 meters thick (Webster, 1980). This discrepancy reflects variations in the crustal stability of the area which is associated with Pennsylvanian/Permian tectonism. In essence the Wichita Mountain block (including the Meers Valley) functioned as a relatively stable area, little affected by subsidence whereas the Anadarko Basin was subsiding very rapidly.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The Meers Valley is an exhumed Late Pennsylvanian-Early Permian Valley which lies between the Wichita igneous complex (to the South) and the Slick Hills (to the north). The Meers Valley received sediments from both the Wichita igneous complex and the Slick Hills. Sediments were deposited into the valley by alluvial fans. The sediments were first derived from the southwest and then from the northeast. Sediments were then transported axially to the southeast by a braided stream system (Figure 51).

The Meers Fault had several periods of movement. The first uplifted the Wichita complex. Sediments from this uplift, possibly the Pennsylvanian granite wash, were transported northward into the Anadarko Basin.

The fault provided an avenue for erosion which initiated the formation of the valley. The valley continued to deepen as the gabbro (uplifted block) adjacent to the Meers Fault eroded easily in comparison to the limestone block. Alluvial detritus (granite-clast conglomerates) from the igneous complex became trapped by the northern block which became increasingly higher topographically (in comparison to the valley).

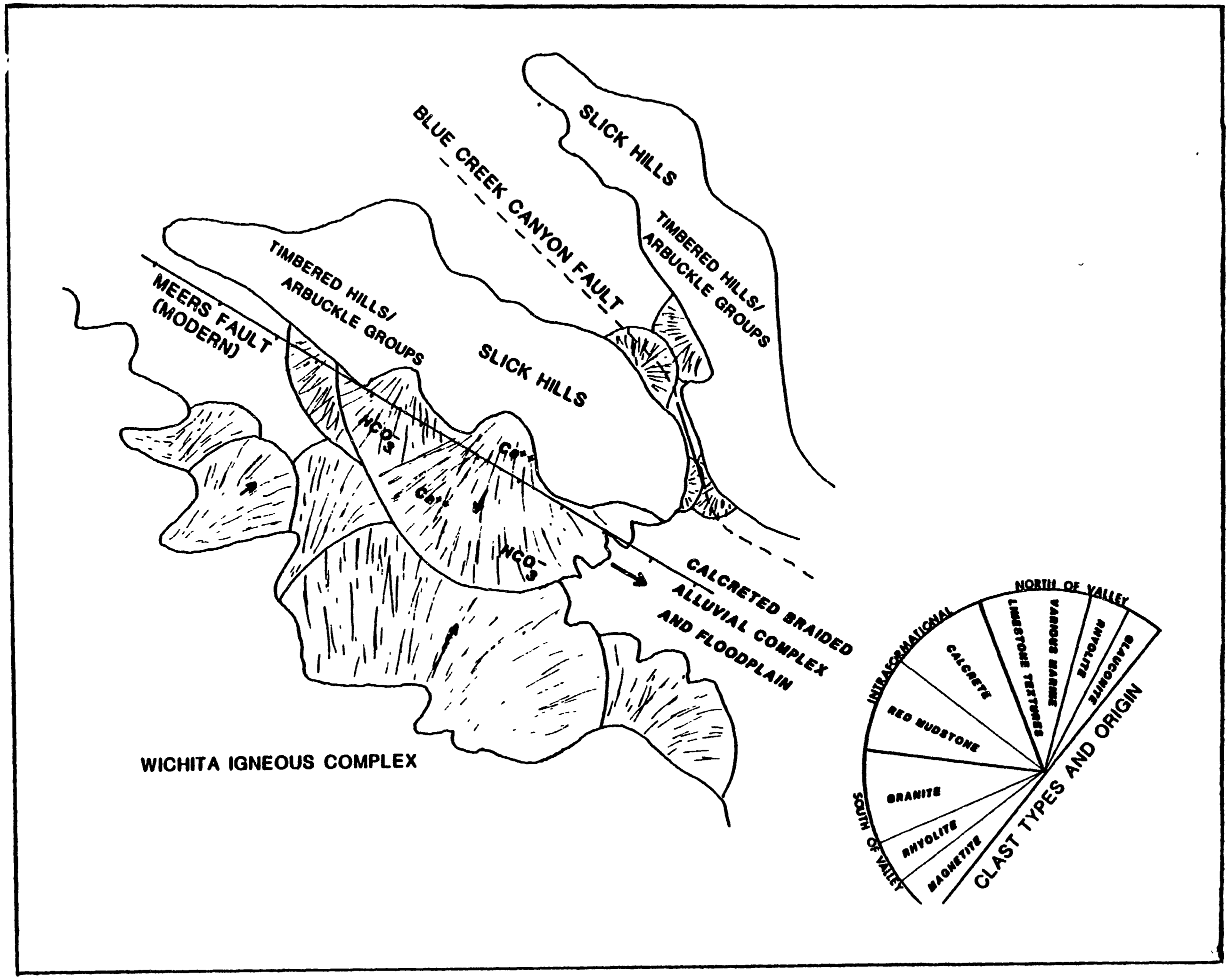


Figure 51. Plan View of the Meers Valley in Late Permian Time

It is suggested that the granite-clast conglomerates are Late Pennsylvanian in age because:

1) The lack of calcretes in these rocks possibly indicates a nonarid climate.

2) The presence of coal in the Pennsylvanian granite wash (which may be a facies equivalent of the conglomerates) also indicates a more humid climate.

3) Tectonic activity ended in Late Pennsylvanian according to many authors.

The granite-clast conglomerates are not very well-cemented. Cements that are present include clays and hematite which originated from the breakdown of the minerals in the granite.

In Early Permian time the climate became increasingly arid and the limestone block became increasingly resistant relative to the igneous block. The relief on the limestone block became sufficient to supply detritus for alluvial fan formation. Limestone-clast conglomerates were deposited on gabbro and granite-clast conglomerates in the valley.

Rejuvenated and reversed movement on the Meers Fault uplifted the limestone block. Giant boulders of limestone and dolomitized fault breccia tumbled/slid? onto the granite- and limestone-clast conglomerates. After tectonics ended, deposition of relief-related limestone-clast conglomerates resumed.

It is suggested that the limestone-clast conglomerates may be as old as Upper Pennsylvanian because authors have designated Late Pennsylvanian time as the end of tectonic activity. However, as stated before, these authors were unaware of the megabreccia deposits. If they had known of them they may have extended the tectonic time boundary into Early Permian time.

The megabreccia deposits contain blocks of Kindblade dolomite as well as dolomitized fault breccia. The nearest source of the Kindblade Formation is over 2 km to the northwest, suggesting at least 2 km of left-lateral movement along the Meers Fault during and since deposition of the megabreccia.

The limestone-clast conglomerates are largely cemented with calcrete. Other cements in the limestone-clast conglomerates include other various calcium carbonate textures: fibrous calcite, anhedral spar, poikilitic textures, and pendant cements; and hématite, barite, and pyrite. The Cambro-Ordovician limestones in the Slick Hills were the source of the calcium carbonate.

The granite/limestone-clast conglomerates, sandstones, and shales in the southeastern portion of the valley were deposited by an axial drainage system. Clasts were eroded from previous deposits on both of the valley slopes and redeposited as mixed deposits in the southeastern portion of the valley. A braided stream/flood plain complex transported finer sediments further to the southeast. These deposits may have been deposited simultaneously with or after the limestone-clast conglomerates. These deposits are mostly cemented by calcrete and other calcium carbonate cements and hematite.

Calcrete development requires a slow rate of sedimentation, semiarid climate-relatively little rainfall (10 to 60 centimeters per year), little erosion, and a sufficient amount of time. Calcretes in the Meers Valley range from young to old age, indicating that these rocks must have been deposited slowly under semiarid conditions in a relatively stable geomorphic environment.

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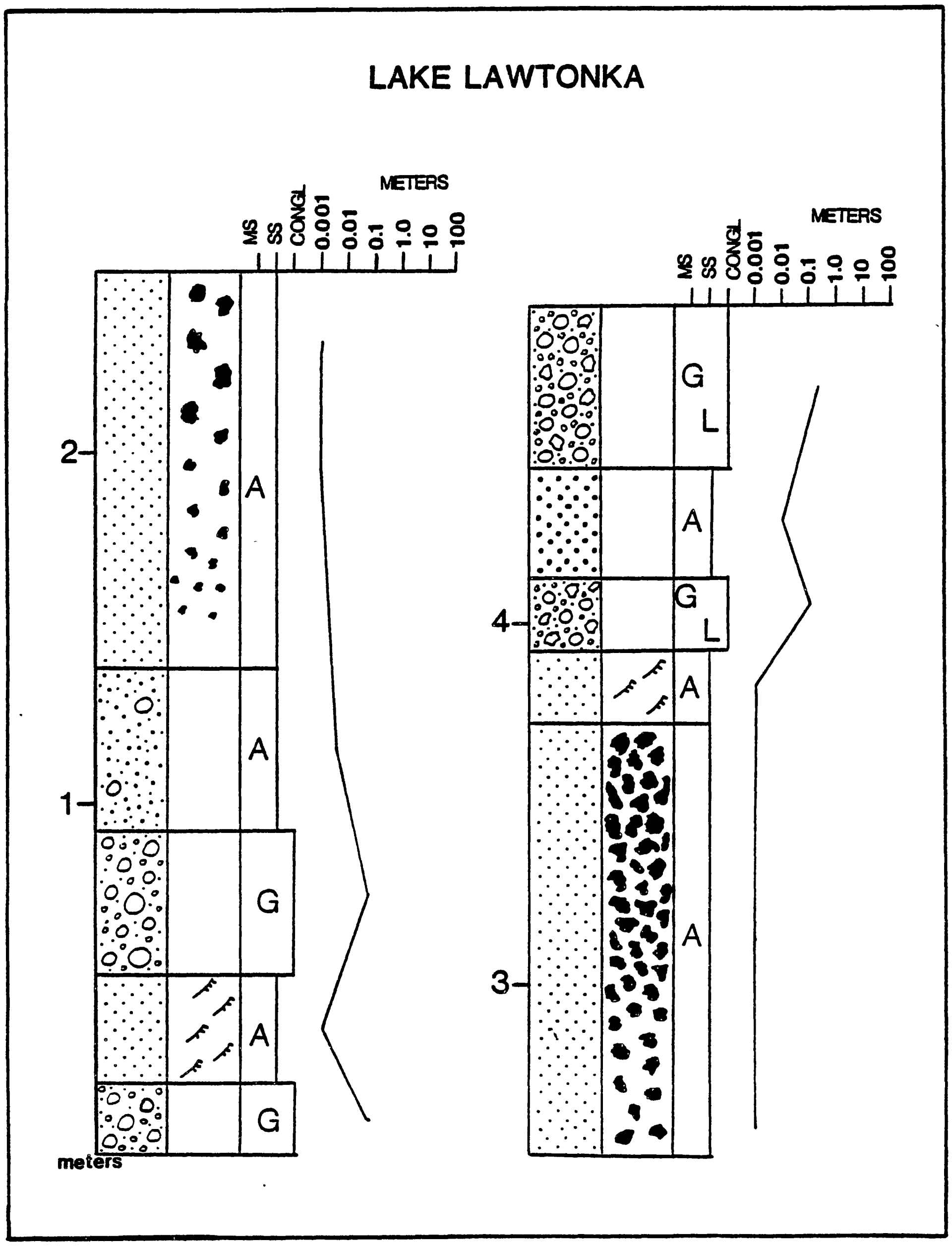
APPENDIXES

APPENDIX A

STRATIGRAPHIC SECTION OF ONE OUTCROP AT LAKE LAWTONKA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APPENDIX B

STRATIGRAPHIC SECTION OF SECTION ONE ON

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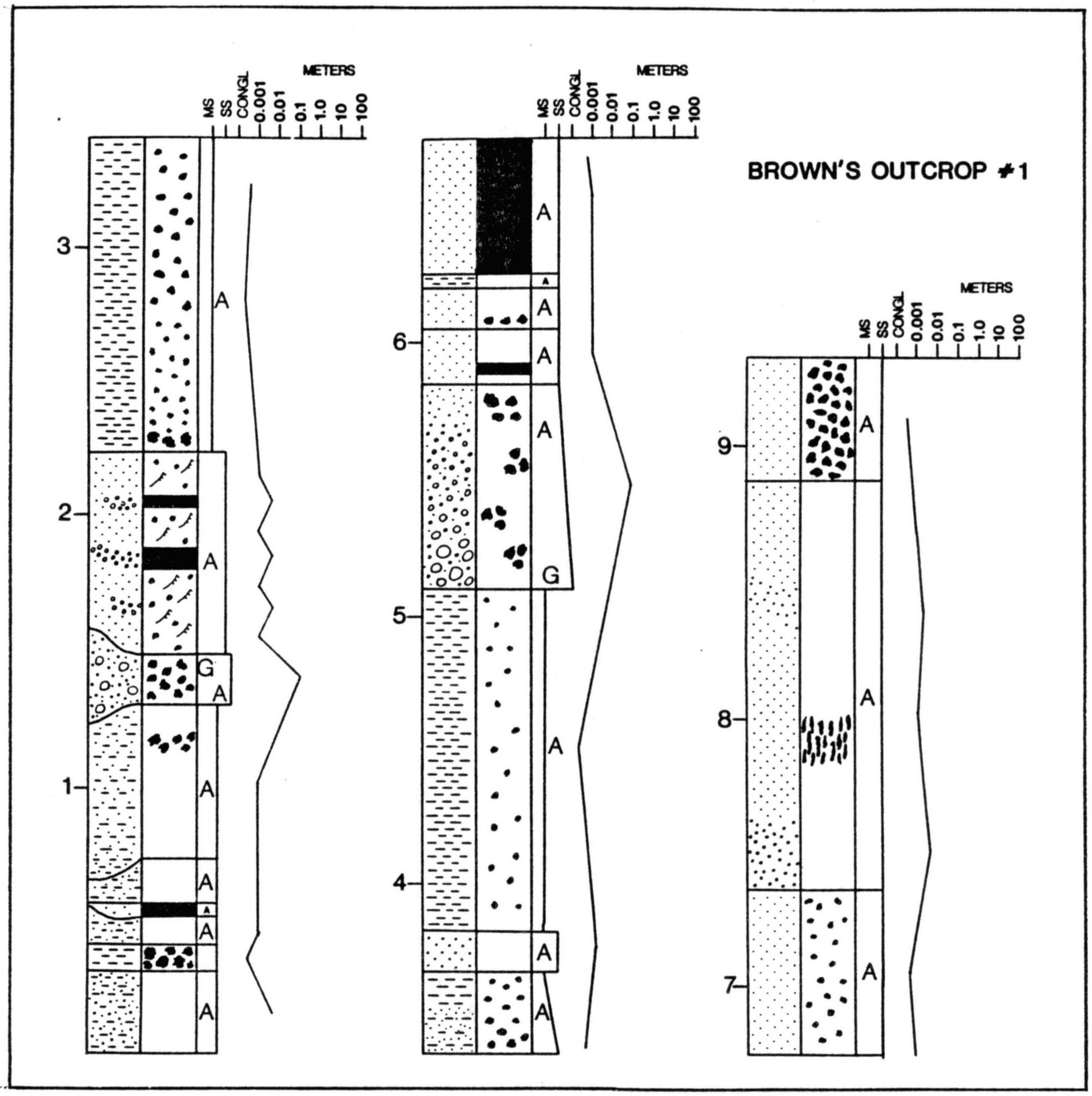
T3N, R12W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VITA ∂

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